Energy Conservation Building Code (ECBC) USER GUIDE

DRAFT (PLEASE DO NOT CITE OR CIRCULATE)

MARCH 25, 2009

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ENERGY CONSERVATION BUILDING CODE (ECBC) USER GUIDE

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March 20, 2009

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USAID ECO-III PROJECT

The Energy Conservation and Commercialization (ECO) Program was signed between the Government of India (GOI) and USAID in January 2000 under a Bilateral Agreement, with the objective to enhance commercial viability and performance of Indian energy sector and to promote utilization of clean and energy-efficient technologies in the sector.

Following the enactment of the Energy Conservation Act 2001, ECO-I Project supported GOI in the establishment of the Bureau of Energy Efficiency (BEE). Support to BEE was provided to set up procedures and authorities, establish office facilities and assist in several activities leading to the development of BEE's Action Plan including thrust area such as the development of an energy auditor certification program.

ECO-II Project provided BEE with necessary technical assistance and training support to implement two thrust areas of the Action Plan. The first area was to develop the Energy Conservation Building Codes (ECBC) for the five climatic regions of India, and the second was to support Maharashtra Energy Development Agency in developing strategies for energy conservation and implementation of selected programs.

Since November 2006, International Resources Group (IRG), with support from its partners IRG Systems South Asia, Alliance to Save Energy and DSCL Energy Services, has been implementing the ECO-III Project by working closely with BEE, Gujarat Energy Development Agency, Punjab Energy Development Agency, international experts, academic institutions, and private sector companies.

The major objective of the ongoing ECO-III Project is to assist BEE in the implementation of the Energy Conservation Act. The focus areas include: 1) development of the Energy Conservation Action Plan at the state level, 2) implementation of the Energy Conservation Building Code, 3) improvement of energy efficiency in existing buildings and municipalities, 4) inclusion of energy efficiency subjects in architectural curriculum, and 5) enhancement of energy efficiency in small and medium enterprises.

FOREWORD

To be Added

March 2009 (Ajay Mathur)

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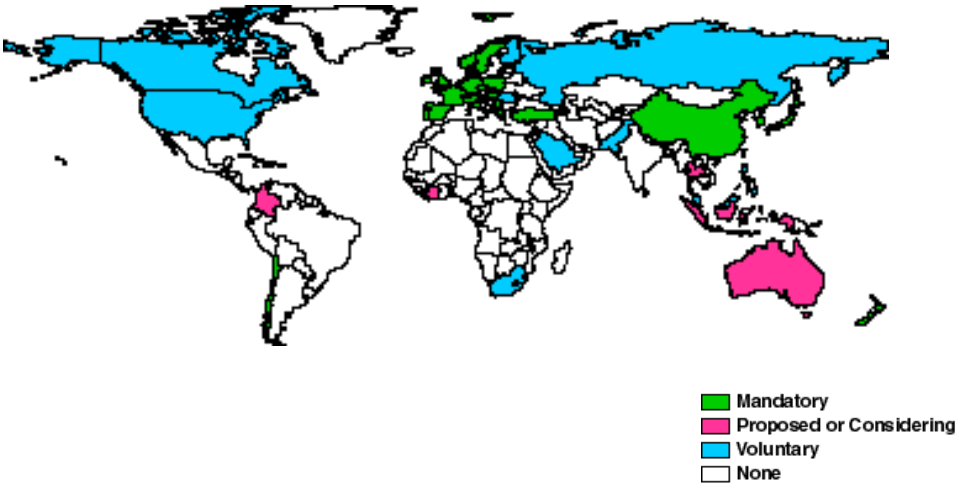
March 2009 (Satish Kumar)

PREFACE

The heating, cooling, ventilation, and lighting requirements in a commercial building account for 30% to 40% of primary energy worldwide. India's building sector is growing at a rapid pace and is the third largest consumer of energy, after the industrial and agricultural sectors. National estimates show that the building energy use in India is increasing by over 9% annually, which greatly outpaces the national energy growth rate of 4.3%. It is projected that the commercial building sector alone will grow at 7% annually up to the year 2030 in India. Currently, India has only 200 million square meters of installed base, but, by 2030, it is expected that 8,690 million square meters of additional commercial space will be constructed. This trend has already begun to strain the power sector with energy shortages of over 11.3% in peak demand and a 7% supply deficit leading to power cuts and rolling blackouts that are endemic in most cities and towns of the country.

Buildings are typically designed to last 50 to 100 years, so their energy performance can have enduring effects. An improved energy efficiency scenario translates into reduced operating costs and a reduced demand for energy. Energy cost ranges between 10 to 15% of operating income in commercial buildings. Further, energy consumption studies conducted in several office buildings, hotels, and hospitals indicate an energy savings potential of 20 to 50% in end-uses such as lighting, ventilation and cooling, building services operation, etc. This represents a vast, untapped saving potential attributable mainly to lack of an effective delivery mechanism for energy efficiency with tangible financial benefit to the individual as well as the nation. Apart from burdening our energy infrastructure, the building industry and our urban growth trends increase environmental degradation, greenhouse gasses, and overall ecological footprints of our towns and cities. Mandating the energy performance of the building envelope, lighting, heating, ventilation and air conditioning (HVAC) and other building systems through codes can standards can offer national governments many important benefits.

By 1999, twenty-two countries had mandatory building energy efficiency standards, three had voluntary standards, and many others had proposed or were considering standards. These existing building energy efficiency standards are estimated to yield a wide range of energy, environmental and economic benefits. For example, According to the U.S. Department of Energy (DOE), if all 50 U.S. states adopted and fully implemented American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90.1-1999, a model energy code for commercial buildings, then building owners and tenants would lower their utility bills by $110 million the first year and save $5.7 billion over 10 years. The country would save 16 trillion British thermal units (Btu) of energy that first year and almost 800 trillion Btu cumulatively over 10 years.



Status of Building Energy Efficiency Standards Worldwide

Source: Lawrence Berkeley Lab (http://eetd.lbl.gov/EA/ecsw/ecsw.html)

In India, the Energy Conservation Building Code (ECBC) was mandated by the Energy Conservation Act of 2001, and lays down the foundation of energy policy for the buildings sector in India. The code specifies the energy performance requirements for all future commercial building construction in India. It is aimed at reducing building energy consumption and optimizing energy use in buildings. It is planned that the code shall be mandatory (once enforced) for commercial buildings or building complexes. It is proposed to make the ECBE mandatory for all new building that have a connected load of 500 kW or greater or a contract demand of 600 kVA or greater. The code is also applicable to all buildings with a conditioned floor area of 1,000 m_2 (10,000 ft_2) or greater.

Computer simulation exercises indicate that ECBC-compliant buildings can use 40 to 60% less energy than similar baseline buildings. It is estimated that the nationwide mandatory enforcement of the ECBC will approximately yield annual saving of 1.7 billion kWh. The national code is expected to overcome market barriers, which otherwise result in the under investment in building energy efficiency. This is primarily due to the fact that builders have little incentive to invest in energy efficiency since they pay the up-front costs and not the energy usage bills of the buildings they develop, and buyers are not able to easily estimate the saving potential from investing in energy efficient construction and technologies. The ECBC and energy efficient building design can help the building owners and facility managers not only aim to reduce operating costs, but can also contribute towards increasing the reliability and availability of electricity, improve building occupant comfort, reduce environment degradation and help the flight against global warming by lowering greenhouse gas emissions.

We have designed the User Guide to be modular and easily expandable. We encourage feedback, which will help us improve its usability.

-- Development Team

COMPARISON OF INTERNATIONAL BUILDING ENERGY STANDARDS

Prepared by Meredydd Evans and Bin Shui, Pacific Northwest National Laboratory

With support from the U.S. Department of Energy

Buildings account for about 1/3 of all the energy consumption in the world, and much of this consumption footprint is locked in through the design and construction of the building.[1] Building energy standards are an important tool to improve energy efficiency in new buildings. For example, China's residential energy standard requires new buildings to be 65% more efficient than buildings from the early 1980s. In the U.S., building energy codes[2] save over $1 billion in energy costs per year, and this figure is growing.[3] Denmark adopted one of the first comprehensive building energy codes in 1961, and it has seen average household energy consumption per unit of space drop substantially since then.[4] Building energy standards set requirements for how energy efficient a building will be. Standards vary quite a bit between countries in several respects including the extent of their coverage, the specific requirements, means of attaining compliance and the enforcement system. This summary provides an overview of some key trends in building energy standards, and what this may mean for India.

Extent of Coverage

Building energy standards at a minimum usually cover insulation and thermal and solar properties of the building envelope (the walls, roofs, windows and other points where the interior and exterior of a building interface). Most standards also cover heating, ventilation and air conditioning, hot water supply systems, lighting, and electrical power. Some cover additional issues such as the use of natural ventilation and renewable energy, and building maintenance. In some countries, not all the issues are considered in a single standard. For example, the Chinese standards include lighting in a separate document. Within these broad categories, there are also numerous differences in what the specific requirements cover. Some countries have significant detail about the need to minimize condensation on insulation. Some countries (like India or Japan) have detailed requirements based on different types, sizes or orientations of buildings, for example, while others have simpler requirements for a broader range of buildings. The U.S., India and Canada all have commercial building energy codes derived from standards produced by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), although specific requirements in each country vary. European Union countries are all required to adopt legislation harmonized with the Directive on Energy Performance in Buildings, which provides guidelines for the performance of buildings including the envelope, HVAC, lighting (in non-residential), building orientation and passive solar systems.

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[1] *This report is primarily based on a series of country reports describing building energy codes in the Asia-Pacific region that the Pacific Northwest National Laboratory prepared with U.S. Department of Energy support under the Asia-Pacific Partnership on Clean Development and Climate.*

[2] *Some countries refer to their building energy regulations as codes and others call them standards.*

[3] *Please see www.energycodes.gov for details.*

[4] *Jens Lausten. 2008. Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings. International Energy Agency, Paris.*

Comparison of Elements Covered in Selected Commercial Building Standards and Codes

	Australia	Canada	China	India	Japan	Korea	U.S. (ASHRAE 90.1 2007)
Envelope	X	X	X	X	X	X	X
HVAC	X	X	X	X	X	X	X
Service Hot Water and Pumping	X	X	N.A.	X	X	X	X
Electrical Power	X	X	N.A.	X	N.A.	X	X
Lighting	X	X	N.A., in a separate standard	X	X	X	X
Performance -Based Alternative	X	X	N.A.	X	X	X	X

Not all standards and codes cover the same types of buildings either. For example, in India, the Energy Conservation Building Code (ECBC) covers commercial and multi-family residential buildings, but not small residential buildings; this is also true of the standards in Russia, Ukraine and Kazakhstan, for example. In Japan, there are standards for both residential and commercial buildings, but the buildings must have at least 2,000 square meters of floor space to be covered. Most countries that regulate both commercial and residential construction for energy efficiency have separate standards for each, although countries categorize the buildings differently. In India, Australia, Canada and the U.S., the codes consider commercial buildings to include multi-family residential buildings, while in China and Japan, the residential standards regulate such multi-family residences. This difference is important because typically the commercial building requirements are somewhat more complex and cover more issues than those for residential buildings.

Specific Requirements

The actual efficiency requirements for new buildings vary between countries. While it would not be possible to highlight the full range of variation in a summary of this size, a few examples may help to illustrate this point. The table below highlights differences between the requirements for several building components in India, Australia, China and the U.S.

Snapshot of Building Energy Efficiency: Maximum U-Factors and Lighting Power Densities in the U.S., China and India

Units: W/(m²·K) for U-factors

Building Components	U.S. Miami	China Hainan	India New Delhi	Australia Darwin
Roof	0.358	0.9	0.409 for most buildings; 0.261 for 24-hr buildings	0.313
Wall	0.642 to 3.293	1.5	0.44	0.556
Vertical Glass Windows (SHGC)	0.25	0.35 to 0.60	0.20-0.25	0.09
Lighting (Power Density in w/m²)	10.8	11	10.8	7 or 10

Notes: This table assumes that we are comparing a 10-story commercial office building in similar climate zones in each country. The representative cities used for the comparison are Miami in the U.S., Hainan Province in China, and New Delhi in India. SHGC stands for solar heat gain coefficient and it represents the ratio of solar heat that can penetrate through a window. WWR stands for window to wall ratio.
Sources: *ASHRAE 90.1-2007, ECBC 2007, China's Design Standards for Energy Efficiency of Public Buildings 2005 and the Building Code of Australia 2007.*

In general, the lower the number represented in this chart, the more efficient the component will be. However, because this chart is looking at one building type in one climate zone, extrapolating these results to a national level requires some care. For example, the U.S. U-values shown are quite different than the requirements applicable in other U.S. climate zones, where more efficient envelopes are mandatory.

Means of Attaining Compliance

Building energy standards typically provide property owners with some degree of flexibility in meeting the energy efficiency requirements. This is important because it means that the standard can be more stringent without impinging too severely on the ability of property owners to adapt buildings to their needs. There are several approaches to providing this flexibility. In many countries, including India, the U.S., Canada and Australia, the codes have four classes of requirements. The first are mandatory requirements that must be satisfied regardless of any other factors for a building to be considered in compliance. The majority of these codes are then made of up prescriptive requirements, which are similar to the mandatory requirements in that they provide specific values and details. However, building designers may be allowed to "trade-off" some of the prescriptive requirements with others regarding the building envelope. The codes then provide rules on what can be traded-off and how. Finally, these codes also provide an option for compliance based on building energy performance instead of the prescriptive requirements. This last option would allow a building designer to install less efficient windows but a more efficient air conditioning system if the total designed energy use falls within the required norms. There are several approaches to establishing the baseline for comparison under the building energy performance method. The UK uses a total carbon footprint of the building

(called the Carbon Index Rating)5, the U.S. uses the cost as its reference metric, while some other countries define the characteristics of a reference building for the comparison.

Korea takes a different approach, establishing mandatory requirements and points for a whole range of energy issues related to buildings. Each new building must have a minimum of 60 points. Buildings that exceed the minimum point requirement may be eligible for certain benefits, such as relaxation of certain zoning rules.

Enforcement Systems

Enforcement is critical for the standard to have an effect. Not all countries have mandatory building energy standards. India, for example, has a voluntary code. Japan's standard is also technically voluntary, although Japan has recently adopted penalties for non-compliance that blur this distinction. The U.S., Canada and Australia all adopt building standards at the local level. Not all jurisdictions in the U.S. and Canada have adopted their nation's model building energy code.

Some important issues regarding enforcement and the related impact of the code on energy use include: the point of compliance (design and/or construction stage), how buildings are checked and by whom, penalties and other incentives for compliance, training and information on the code, compliance tools such as code compliance software and inspection checklists, equipment and material testing and ratings.

In the U.S., Canada, Australia and Korea, for example, the building design must be approved and inspectors check the building for compliance at least once during construction. In Japan, parts of Europe and the former Soviet Union, the checks only occur at the building design stage. China uses a combination of government employees and certified companies to check building designs and inspect the buildings for compliance. There is no single answer as to which system produces the highest level of compliance. For example, Japanese officials believe that Japan attains a high level of compliance in actual construction because Japan has a very well developed system of training and information dissemination on the building energy standards. Studies in the U.S. have shown that there, physical inspections result in much higher compliance rates.

The stringency of the national system for testing materials and equipment for their energy efficiency properties can also have a marked impact on the final energy consumption of a building. Most countries have a system of certified laboratories that test materials and equipment (like windows and air conditioners), and rate them for efficiency. These ratings then determine if the equipment in a building meets the building energy standard. Testing procedures vary between countries, and there is anecdotal evidence that even in countries with well established systems, ratings can differ by 10% or more based on the testing procedures.

Building energy standard compliance rates vary significantly between countries. What constitutes compliance may also vary, and not all countries consistently publish compliance data. That said, countries usually have lower compliance rates soon after they adopt or revise a standard, and when their enforcement system is not fully developed.

Options for India to Consider

India has taken a purposeful step toward improved building energy efficiency in adopting the Energy Conservation Building Code. The next step is implementing this code, which could require concerted efforts both at the state and national levels. States would need to decide to adopt the code. The national government could also help with this learning process by requiring

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[5] R.E. Horne et al. 2005. *International Comparison of Building Energy Performance Standards.* Centre for Design, RMIT University, Melbourne, Australia.

that all new government buildings meet the building energy code. For example the national government might provide tools to help states and local jurisdictions with enforcement. India has a well-developed system to enforce other types of building codes, and it might use this system for enforcing the building energy code as well. Building energy inspectors at the local level might need training, and local jurisdictions could hire some staff to handle the additional workload. India could also try to simplify the implementation task by developing code compliance software that allows building developers and inspectors to easily check the building design for compliance. Such software could also be designed to automatically develop inspection checklists. As India gains experience with implementing its code, it might want to modify the code periodically. Many countries have found that establishing a regular timetable for such modifications can allow many stakeholders to have input into the process, which in turn, makes the code more feasible to implement. Indian consumers could benefit from this process as the energy costs in new buildings decline at the same time that the environmental footprint of these buildings grows smaller.

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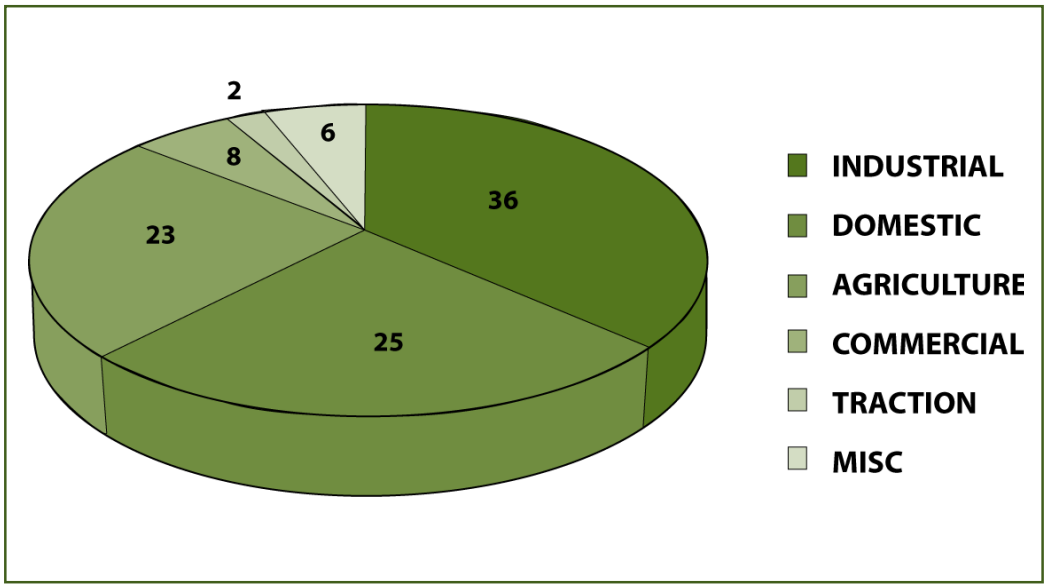
1 PURPOSE

The Energy Conservation Building Code (ECBC) provides minimum standards for energy-efficient commercial and other high-rise residential buildings and their systems. The commercial buildings sector represents eight percent of utility electricity consumption in India (**Figure 1: Consumption of Electricity by SectorFigure 1**). The ECBC was developed as a first step towards producing significant savings in this sector. This guide is developed to provide expanded interpretation, examples, and helpful tools to aid in applying ECBC compliance requirements during building design and construction.

Figure 1: Consumption of Electricity by Sector



The ECBC is the result of extensive work by the Bureau of Energy Efficiency (BEE) and its working groups. It is written in code-enforceable language and reflects the views of the manufacturing, design, and construction communities as an appropriate set of minimum requirements for energy efficient building design and construction.

BEE reviewed building construction methods across the country and evaluated various energy efficient design-build practices that could yield a reduction in building energy consumption. In addition, detailed life-cycle cost analyses were also conducted to ensure that the ECBC requirements reflect cost-effective and practical efficiency standards across different climate zones in India. The result is a broad code with appropriate requirements for commercial buildings according to their site conditions and climate zones. The ECBC specifies reasonable design practices and technologies that minimize energy consumption without sacrificing the comfort of productivity of the occupants.

This guide is designed to help owners, designers, engineers, builders, inspectors, examiners, and energy consultants comply with and enforce India's energy efficiency standards for commercial buildings, as described in the ECBC. The guide follows the nomenclature of the ECBC, is written as both a reference and an instructional guide, and can be helpful for anyone who is directly or indirectly involved in the design and construction of commercial buildings.

TIP: Using the Guide

It is best to first review Chapters 1 through 3 to understand basic ECBC requirements and their application to all buildings and building systems. The subsequent chapters discuss specific systems (Envelope, Heating, Ventilation and Air Conditioning (HVAC), Service Hot Water Systems, Lighting, and Electrical Power) and can be referenced individually or reviewed together for a complete understanding of the code. Each chapter has three parts:

A brief overview of the respective system covered in the chapter

The ECBC criteria for the system, including:

- Mandatory provisions
- Compliance examples
- Helpful tips
- Frequently Asked Questions (FAQs) and Answers

Compliance Sheets are incorporated throughout the User Guide and may be copied and used for documenting compliance.

An expanded list of abbreviations, terms and definitions can be found in Appendix A.

2 SCOPE

The ECBC is a code which covers the design and construction of new buildings, additions and major renovations to existing buildings, building systems, and energy-using equipment. The specific building systems covered are the building envelope; heating, ventilating & air conditioning (HVAC); service hot water and pumping; lighting; and electrical power. Review the following checklist to determine if your building is required to comply with the ECBC. The building is:

- Either a multi-family building with four or more stories, a commercial building, or a building complex, with a connected load of 500 kW or greater, or a contract demand of 600 kVA or greater.
- A new building or building complex with conditioned floor area of at least 1,000 m2.
- A extension of an existing building, where the addition plus the existing building exceeds 1,000 m^2 of conditioned floor area.
- A renovation or alteration of an existing building where the area of alteration exceeds 1,000 m^2 conditioned floor area

2.1 APPLICABLE BUILDING SYSTEMS

The provisions of this code apply to:

- Building envelopes, except for unconditioned storage spaces or warehouses
- Mechanical systems and equipment, including heating, ventilating, and air conditioning
- Service hot water heating
- Interior and exterior lighting
- Electrical power and motors

2.2 EXEMPTIONS

- The ECBC **DOES NOT** apply to building envelopes for unconditioned storage spaces or warehouses; or equipment and portions of building systems that use energy primarily for manufacturing processes.
- ECBC also **DOES NOT** apply to replacement glass of an existing sash and frame; modifications to building cavities insulated to full depth, and modifications to wall and floors with cavities and where no new cavities are created.
- ECBC shall not be used to circumvent any safety, health, or environmental requirements. If there is a conflict between the requirements of this code, then the safety, health, or environmental codes shall take precedence.

2.3 SAFETY, HEALTH AND ENVIRONMENTAL CODES TAKE PRECEDENCE

Where this code is found to conflict with safety, health, or environmental codes, the safety, health, or environmental codes shall take precedence.

2.4 REFERENCE STANDARDS

National Building Code 2005 (NBC 2005) has been considered as the reference document/standard for lighting comfort levels, HVAC, comfort levels, natural ventilation, pump and motor efficiencies, transformer efficiencies and any other building materials and system performance criteria.

ECBC is presently for adoption on a voluntary basis but may become mandatory with notification by the central and state government in accordance with the Energy Conservation Act 2001.

3 ADMINISTRATION AND ENFORCEMENT

The ECBC includes requirements that address energy-saving opportunities in buildings. The energy consumption requirements of the code have been designed to be flexible enough to allow architects and engineer the ability to comply with the code and meet the specific needs of their projects according to the climate conditions of the site.

3.1 COMPLIANCE REQUIREMENTS

3.1.1 Mandatory Requirements

Mandatory requirements must be followed in every building, regardless of compliance approach. Apart from meeting mandatory requirements, inspection at site coupled with proper installation technique is essential for meeting the intent of the building energy code.

Compliance with the requirements of this energy code shall be mandatory for all applicable buildings discussed in Section 2.

3.1.2 New Buildings

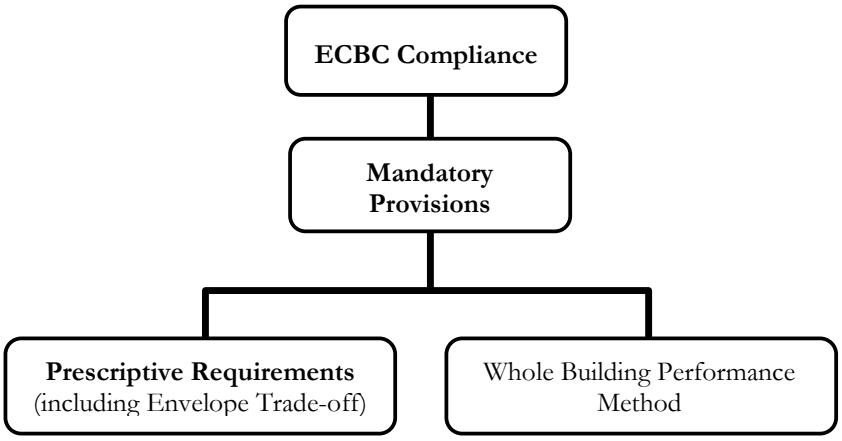
The ECBC compliance procedure requires the building to fulfill a set of mandatory provisions related to energy use as well as demonstrate compliance with the specified minimum energy consumption guidelines stipulated for the different building components. The submittal documents include the building plans and specifications that show all pertinent data and features of the building, equipment, and systems in sufficient detail to permit the authorized personnel jurisdiction to verify that the building is compliant. The authority having jurisdiction may require supplemental information necessary to verify compliance with this code, such as calculations, worksheets, compliance forms, manufacturer's literature, or other data.

To maintain flexibility for the design and construction team, ECBC requirements can be met by following one of two methods:

1) Prescriptive Method, which illustrates prescribed minimum energy efficiency for each component of the proposed building.

2) Whole Building Performance Method, which requires an approved computer software program that models a proposed building, determines its allowed energy budget under the ECBC, calculates its as-designed energy use, and determines when it complies with the budget. This performance approach is more complicated than the Prescriptive Method, but offers considerable design flexibility. It allows for code compliance to be achieved by optimizing the energy usage in various design components (building envelope, HVAC, lighting and other building systems) in order to find the most cost effective solution.

In addition, all buildings must comply with a set of mandatory provisions, as described in Sections 4.2, 5.2, 6.2, 7.2, and 8.2 of the ECBC. These mandatory provisions are included and explained in their corresponding sections of this guide.



Section 3 outlines compliance options and specifies requirements applicable to all projects. The ECBC requires that general and mandatory provisions always be met in every project. Technical prescriptive requirements are covered in Section 4 through Section 8 which deal, respectively, with the building envelope, HVAC systems; service hot water and pumping, lighting systems, electric transformers, electric motors, power factor correction systems and power distribution system. An alternative compliance method is described in Appendix B: the Whole Building Performance (WBP) or Energy Cost Budget method.

Existing Building Compliance

The Code also applies to certain work in existing buildings. The requirements are triggered when new construction is proposed, such as an addition, or when unconditioned space is converted to conditioned space (that is, heating and/or cooling are added for the first time). The Code applies to additions and alterations much as it does to new buildings: the Mandatory Provisions must always be met; after that, either the prescriptive or whole building performance approach for compliance may be applied. However, in existing buildings there is a general exception to the Code whenever compliance with the requirements can be shown to cause an increase in the building's annual energy use. Compliance details are discussed below for additions, alterations, and changes in conditioned space.

3.1.3 Additions to Existing Buildings

An addition is a new wing or new floor that extends or increases the building floor area or height of a building outside the envelope of the existing building. When building an addition, the additional construction must comply with the ECBC only if the original plus additional conditioned floor area is 1,000 m^2 (10,000 ft^2) or greater, and/or the building has a connected load of 500 kW or a contract demand of 600 kVA or greater. Also, when space conditioning for the addition is provided by existing systems and equipment, those existing systems and equipment do not need to comply with the code. Any new equipment installed must comply with specific requirements of the ECBC as listed in Table 1.

Compliance can be demonstrated for the addition alone, or for the addition together with the entire existing building. If meeting compliance for the addition alone, mandatory and prescriptive requirements must be followed, with the exception of existing space conditioning systems, as noted above. If demonstrating compliance for the existing building and addition together, either the Prescriptive or Whole Building Performance method may be used as if it were a new building. If following the whole building approach, trade-offs can be made between the addition and improvements to the existing building so that the annual energy cost of the existing building plus the proposed addition is less than the existing building plus an addition that exactly meets prescriptive requirements. While the envelope might not meet the prescriptive requirements,

other systems, such as lighting, might be improved using this existing building plus addition approach.

Table 1: Equipment Requirements for Building Additions

Situation	Application of Code
An existing central plant will provide hot and cold water to new fan coils in a building addition.	The Code applies to the fan coils and controls in the addition but not to the existing central plant.
A variable air volume (VAV) air handler in the existing building will provide cool air and outdoor air ventilation to an addition.	The Code applies to the VAV boxes and controls in the addition but not to the existing air handler or the central plant that serves it.
An addition is served by its own single-zone HVAC system.	The Code applies to the HVAC system and controls in the same way that it applies to new construction.

3.1.4 Alterations to Existing Buildings

When making alterations to an existing building, the portions of a building and its systems that are being altered must be made to comply with mandatory and prescriptive requirements – as described above for new construction. Compliance is required only if the conditioned floor area of the building is 1,000 m^2 (10,000 ft^2) or greater, and/or the building has a connected load of 500 kW or a contract demand of 600 kVA or greater.

Specific prescriptive system-related requirements for alterations are described within the respective chapter. The exception to this requirement is that compliance can also be demonstrated by showing that the entire building complies with the ECBC, as if it were a new building.

- The first approach is to show that each system, piece of equipment, or component that is being replaced complies individually with the applicable requirements of Sections 4 - 8. With this approach, each component that is being replaced must separately comply with the Code. There can be no trade-offs among components.

- The second approach is to evaluate the whole building and show that the annual energy consumption, with the proposed alteration, does not exceed the annual energy consumption of a substantially identical alteration that exactly meets all the prescriptive requirements. This approach permits trade-offs between components and equipment as long as the proposed alteration performs as well as if it complied exactly with the prescriptive requirements. The proposed alteration must still comply with the Mandatory Provisions. This approach only applies to alterations that replace or modify more than one system. For instance, this approach cannot be applied when just a water heater is being replaced. When this approach is used, the calculations and performance analysis must be verified by an architect or engineer licensed to practice in the jurisdiction.

3.1.4.1 Building Envelope

Alterations to the building envelope shall comply with the requirements of §**Error! Reference source not found.** for fenestration, insulation, and air leakage applicable to the portions of the buildings and its systems being altered.

Exception to §3.1.4.1: The following alterations need not comply with these requirements provided such alterations do not increase the energy usage of the building:

a) Replacement of glass in an existing sash and frame, provided the U-factor and SHGC of the replacement glazing are equal to or lower than the existing glazing

b) Modifications to roof/ceiling, wall, or floor cavities, which are insulated to full depth with insulation

c) Modifications to walls and floors without cavities and where no new cavities are created

3.1.4.2 Heating, Ventilation and Air Conditioning

Alterations to building heating, ventilating, and air-conditioning equipment or systems shall comply with the requirements of §**Error! Reference source not found.** applicable to the portions of the building and its systems being altered. Any new equipment or control devices installed in conjunction with the alteration shall comply with the specific requirements applicable to that equipment or control device.

3.1.4.3 Service Water Heating

Alterations to building service water heating equipment or systems shall comply with the requirements of §**Error! Reference source not found.** applicable to the portions of the building and its systems being altered. Any new equipment or control devices installed in conjunction with the alteration shall comply with the specific requirements applicable to that equipment or control device.

3.1.4.4 Lighting

Alterations to building lighting equipment or systems shall comply with the requirements of §**Error! Reference source not found.** applicable to the portions of the building and its systems being altered. New lighting systems, including controls, installed in an existing building and any change of building area type as listed in **Error! Reference source not found.** shall be considered an alteration. Any new equipment or control devices installed in conjunction with the alteration shall comply with the specific requirements applicable to that equipment or control device.

Exception to §3.1.4.4: Alterations that replace less than 50% of the luminaires in a space need not comply with these requirements provided such alterations do not increase the connected lighting load.

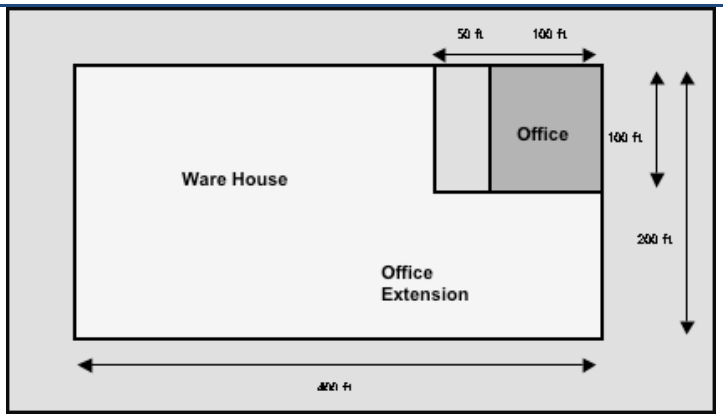
3.1.4.5 Electric Power and Motors

Alterations to building electric power systems and motor shall comply with the requirements of §**Error! Reference source not found.** applicable to the portions of the building and its systems being altered. Any new equipment or control devices installed in conjunction with the alteration shall comply with the specific requirements applicable to that equipment or control device.

Example 1:

Q: An existing warehouse measures 400 ft X 200 ft (125 m X 70m). The warehouse is unconditioned, but administrative offices are located in a 100 ft X 100 ft (30m X 30m) corner. The offices are served by a single-zone rooftop packaged HVAC system that provides both heating and cooling. The owner wants to expand the administrative offices into the warehouse. The new office space will convert an area that measures 100 ft X 50 ft (30m X 15m) from unconditioned to conditioned space. The existing HVAC system has sufficient capacity to serve the additional space. However, new ductwork and supply registers will need to be installed to serve the additional space.

Does the Standard apply to this construction project?



A: The Code applies to the 100 ft X 50 ft (30m X 15m) space that is being converted from unconditioned to conditioned space. However, the Standard does not apply to the existing office or the existing warehouse space. The new lighting system installed in the office addition must meet the requirements of Section 7. The walls that separate the office addition from the unconditioned warehouse must be insulated to the requirements of Section 4. The exterior wall and roof are exterior building envelope components and must meet the requirements for nonresidential spaces. The existing HVAC system does not need to be modified, but the ductwork extensions must be insulated to the requirements of Section 5.

3.2 COMPLIANCE APPROACHES

Prescriptive Method

The ECBC is primarily a set of prescriptive requirements for building systems and components. Compliance with the code can be achieved by meeting or exceeding the specific levels described for each individual element of the building systems, which are covered.

1. The one exception to this is for the building envelope. As explained in Chapter 4 of this guide, envelope system compliance can be achieved by: meeting or exceeding the efficiency of individual elements in the envelope; or
2. Trading off the efficiency of one envelope element for another – with a resulting envelope system that achieves the level of efficiency required by the code.The envelope trade-off equation is found in Section 12: Appendix D of ECBC.

Whole Building Performance Approach

Use of energy simulation software is necessary to show ECBC compliance via the Whole Building Performance Method. Energy simulation is a computer-based analytical process that helps building owners and designers to evaluate the energy performance of a building and make it more energy efficient by making necessary modifications in the design before the building is constructed.

These computer-based energy simulation programs model the thermal, visual, ventilation and other energy-consuming processes taking place within the building to predict its energy performance. The simulation program takes into account the building geometry and orientation, building materials, building façade design and characteristics, weather parameters, indoor environmental conditions, occupant activities and schedules, HVAC and lighting system and other parameters to analyze and predict the energy performance of the buildings. Computer simulation of energy use can be accomplished with a variety of computer software tools and in many cases may be the best method for guiding a building project to be energy-efficient.

However, this approach does require considerable knowledge of building simulation tools and very close communication between members of the design team.

Appendix B of the ECBC describes the Whole Building Performance approach for complying with the code. This method involves developing a computer model of the proposed design and comparing its estimated energy consumption to a predetermined energy budget for that building (See Figure 2). This energy budget represents the upper limit of energy use allowed for that particular building under a scenario where all the ECBC prescriptive requirements were adopted. The 'Energy Budget' for the proposed building becomes the Standard Design, or "base case criteria," as described in detail in Appendix B of the ECBC. Code compliance will be achieved if the proposed energy budget is no greater than the allowed energy budget. Three basic steps are involved:

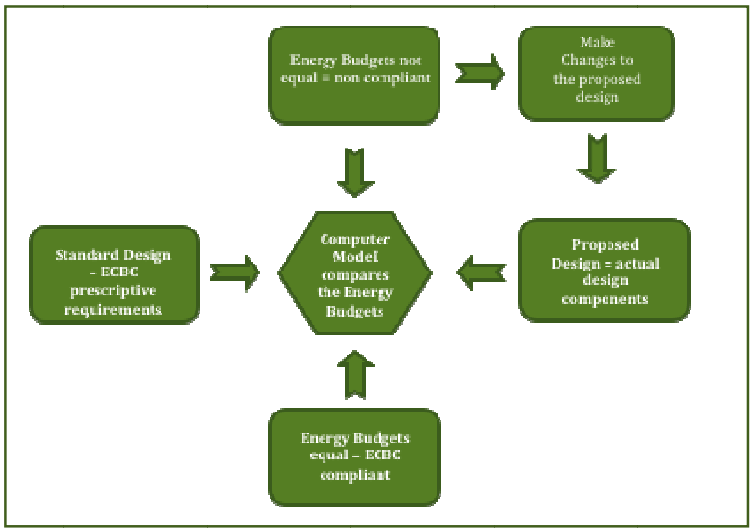
1. Design the building with energy efficiency measures that are expected to be sufficient to meet the energy budget. (The prescriptive approach requirements provide a good starting point for the development of the design.)

2. Demonstrate that the building complies with the mandatory measures (See sections 4.2, 5.2, 6.2, 7.2, and 8.2).

3. Using an approved calculation method, model the energy consumption of the building using the proposed features to create the proposed energy budget. The model will also automatically calculate the allowed energy budget for the proposed building.

If the proposed energy budget is no greater than the allowed energy budget, the building complies.

Figure 2: Design Process for the Whole Building Performance Method


Energy Budgets not equal = non compliant
Make Changes to the proposed design
Standard Design – ECBC prescriptive requirements
Computer Model compares the Energy Budgets
Proposed Design = actual design components
Energy Budgets equal – ECBC compliant

The biggest advantage of using this approach is that it enables the design-build team to make trade-offs between building systems in order to identify the most cost effective and energy efficient design solution. For instance, the efficiency of the indoor lighting system might be improved in order to justify fenestration design that does not meet the prescriptive envelope requirements.As long as total energy use considering all installed components does not exceed the allowed budget, the trade-off is acceptable.

With either the prescriptive or the performance methods, compliance can be only be achieved by meeting the general and mandatory provisions of each technical section. Then compliance can be achieved when the total energy consumption of the proposed building is demonstrated to be less than the consumption of a building that complies with the prescriptive requirements of the code.

NOTE: For a detailed description of the computer simulation process and details please refer to the 'Energy Simulation Tip Sheet' which can be accessed at: http://eco3.org/downloads/002-Implementationof ECBC/Energy Simulation (Public Version).pdf

3.3 ADMINISTRATIVE REQUIREMENTS

Administration and enforcement of the ECBC is carried out by the local authority having jurisdiction. This authority is responsible for specifying permit requirements, code interpretations, approved calculation methods, worksheets, compliance forms, manufacturing literature, rights of appeal, and other data, to demonstrate compliance.

The authority having jurisdiction will need to receive plans and specifications that show all pertinent data and features of the building, equipment, and systems. This should be provided at a sufficient level of detail to verify that the building complies with the all the requirements of the ECBC. The compliance forms can be found in Appendix G of the ECBC.

The process of designing ECBC compliant buildings will include different stages that begin with the design process, obtaining a building permit, completing the compliance submittals, and finally, the construction of the building. The process of complying with and enforcing the ECBC will require the involvement of many parties. Those involved may include the architect or building designer, building developers, contractors, engineers, energy consultants, inspectors, the owner, and third party inspectors. Communication between these parties and an integrated design approach will be essential for the compliance/enforcement process to run efficiently.

An integrated design approach brings together the various disciplines involved in designing a building and its systems and reviews their recommendations in a comprehensive manner. It recognizes that each discipline's recommendations have an impact on other aspects of the building project. This approach allows for optimization of both building performance and cost. Often, the architect, mechanical engineer, electrical engineer, contractors, and other team members pursue their scope of work without adequate interaction with other team members. This can result in oversized systems or systems that are not optimized for efficient performance; for example, indoor lighting systems designed without consideration of day lighting opportunities or HVAC systems designed independently of lighting systems. Design integration is the best way to avoid redundancy or conflicts with aspects of the building planned by others. An integrated design approach allows professionals working in various disciplines to take advantage of efficiencies that are not apparent when they are working in isolation. It can also point out areas where trade-offs can be implemented to enhance resource efficiency. The earlier that integration is introduced in the design process, the greater the benefit.

3.4 COMPLIANCE DOCUMENTS

3.4.1 General

The documents submitted should include sufficient detail to allow thorough review by the code enforcement agency for compliance with appropriate ECBC requirements. Additional information may be requested, if needed, to verify compliance. The compliance forms and worksheets are provided with this Guide and are intended to facilitate the process of complying with the Code. These forms serve a number of functions:

- They help a permit applicant and designer know what information needs to be included on the drawing.
- They provide a structure and order for the necessary calculations. The forms allow information to be presented in a consistent manner, which is a benefit to both the permit applicant and the enforcement agency.
- They provide a roadmap showing the enforcement agency where to look for the necessary information on the plans and specifications.

- They provide a checklist for the enforcement agency to help structure the drawing check process.
- They promote communication between the drawings examiner and the field inspector.
- They provide a checklist for the inspector.

3.4.2 Supplemental Information

In this new and emerging market for energy-efficient buildings and building components, it can be difficult at times to locate and secure the best products for use in construction. This may be because they are not available locally or are too expensive for the owner's budget. It may also be a significant task to determine the energy efficiency properties of products that are not clearly labeled. The ECBC contains default values that can be used for typical products and building assemblies used locally.

As the demand for products grows, there will likely be more competition and choice available to designers. In the meantime, it is important to note that construction technique – i.e. proper air sealing around joints and windows, installation of vapor barriers and insulation, and correct use of shading devices for windows – has a significant impact on energy efficiency along with the energy efficiency of individual components.

Local jurisdictions will determine the specific documentation required to demonstrate compliance. Recommended materials to submit for a permit application include the following:

Building Envelope:

- Insulation materials and R-values
- Fenestration U-factors, SHGC, visible light transmittance (if using the trade-off approach), and air leakage
- Overhang and sidefin details
- Envelope sealing details

HVAC:

- Type of systems and equipment, including their sizes, efficiencies, and controls
- Economizer details
- Variable speed drives
- Piping insulation
- Duct sealing
- Insulation type and location
- Report on HVAC balancing

Service Hot Water and Pumping:

- Solar water heating system details

Lighting:

- Schedules that show type, number, and wattage of lamps and ballasts
- Automatic lighting shutoff details
- Occupancy sensors and other control details
- Exterior lamp efficacy

Electrical Power:

- Schedules that show transformer losses, motor efficiencies, and power factor correction devices
- Electric check metering and monitoring system details

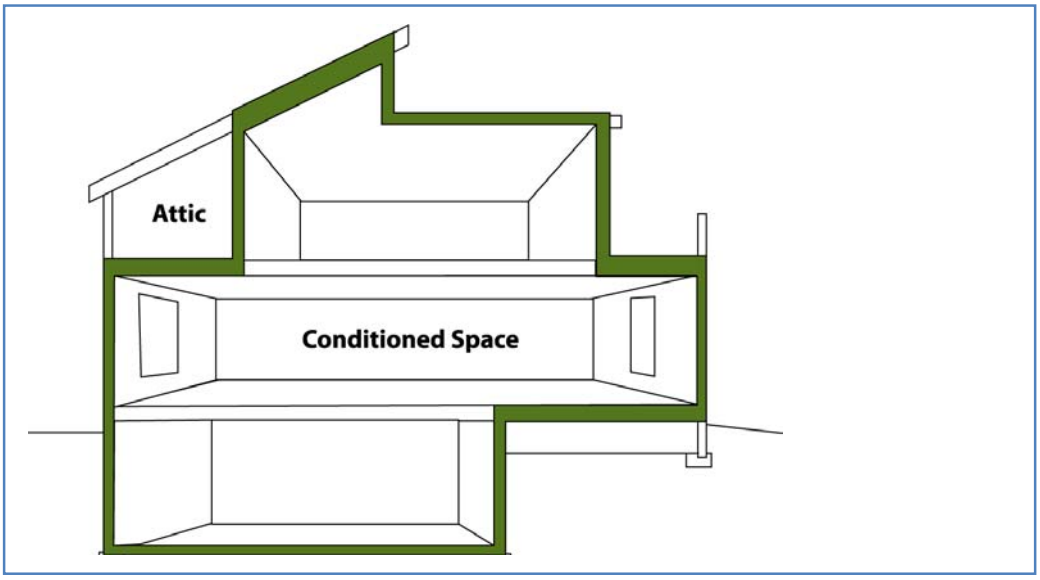
4 BUILDING ENVELOPE

4.1 GENERAL

Overview

This chapter describes requirements for the design of commercial building envelopes. The building envelope refers to the exterior facade, and is comprised of walls, windows, roof, skylights, doors and other openings. Building envelopes consist of opaque components and fenestration components: Opaque envelope components include walls, roofs, floors, floor slabs, basement walls, and opaque doors (See Figure 3). Fenestration components include windows, skylights, ventilators, and doors that are more than one-half glazed. This enclosure protects the building's interior and occupants from the weather conditions and other external elements. While the envelope does not directly use energy, its design features strongly affect the visual and thermal comfort of the occupants, as well as energy consumption in the building. The design of the building envelope is generally the responsibility of an architect, and occasionally of an engineer. The designer is responsible for making sure that the building envelope complies with the code. This chapter is written for the designer as well as other specialists who participate in the design and construction of the building envelope.

Figure 3: Building Envelope



Envelope Design Considerations

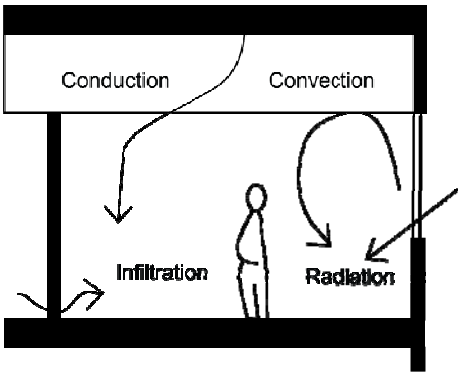
The building envelope is one of the most important factors in designing energy efficient buildings. The envelope and its components, especially windows and skylights, have a significant effect on the heating and cooling needs, which drive a building's energy use. The envelope design must take into consideration both external and internal loads, as well as daylighting benefits. External loads include solar gains, conduction losses across envelope surfaces, and air infiltration, while internal loads include heat gain from lights, equipment, and people.

General Concepts

Building Loads: External and Internal

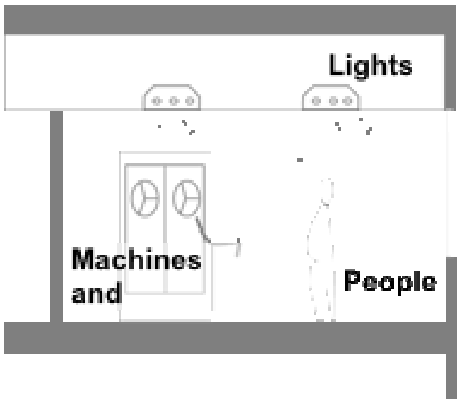
External loads include solar gains through windows, conduction losses due to temperature differences across envelope surfaces, and air leakage or infiltration (See Figure 4). Exterior loads are dynamic. They change as outdoor temperatures and environmental conditions change, as the sun moves through the sky, and as wind changes speed and direction. The building's envelope design directly affects the magnitude and time pattern of external loads. To maintain thermal comfort and minimize cooling/heating loads, the building envelope needs to regulate and optimize heat transfer through roof, walls, windows, doors, other openings and cracks. Solar gains can be controlled by correctly orienting and shading windows and by glazing specifications that limit solar gain while transmitting visible light; conduction loads can be reduced by effective insulation; and infiltration can be controlled by careful caulking and weather-stripping.

Figure 4: External Load



Internal loads are heat gains from lights, equipment and people in the building (Figure 5). They consist of both sensible gains (elevated air temperatures) and latent gains (moisture added to the space). Lighting and most electrical equipment produce only sensible gains, while people and outdoor air ventilation produce both sensible and latent loads. Although internal loads primarily result from the way a building is used, rather than from the envelope design, the introduction of daylight can reduce dependence on electric light and thus reduce internal heat gain from electric lighting.

Figure 5: Internal Load



The ideal building envelope would control exterior loads in response to coincident internal loads to achieve a thermal balance for each set of conditions. When the conditioned building is in a cooling mode, solar gains should be reduced while still admitting daylight. Outdoor air should be introduced during evening hours to cool thermal mass in preparation for the next day's loads. If the building is in a heating mode during the day, solar gains should be increased while heat losses, due to both conduction and infiltration, should be reduced.Therefore in practice, the architects and building designers need to integrate and balance these varying considerations while designing an energy-efficient building

In most buildings, the most significant element of the envelope design is the fenestration. The fenestration design has a considerable impact on solar gains, heat loss and infiltration, and, in combination with interior space planning, determines the potential for daylighting. Finding the right fenestration design and optimizing levels of insulation for each climate and internal load condition is a complicated process. ECBC requirements help by setting minimum levels of thermal performance for all components of the building envelope and limits on solar gain through fenestration, based on climate zone, type of space and occupancy.

Heat Flow in Buildings

The flow of heat through a building envelope varies according to the time of the day, season and path of the heat. For example, in summer, there is heat influx into the building, whereas in winter the built mass loses heat to the outdoor surroundings. The heat transfer may take place through the opaque building's envelope or by way of the outdoor air entering the interior (infiltration).

Buildings experience heat loss to, and gain from, the environment in three principal ways. In *conduction*, heat is transferred directly from the molecules of the warmer building surfaces to the molecules of the cooler solids (such as earth) in contact with the building. In *convection*, molecules from the cooler air absorb heat from a warmer surface, expand in volume, rise and carry it away. In *radiation,* heat flows in electromagnetic waves from the hotter surfaces to the detached; colder ones through any transport medium like empty space. Table 2 describes basic energy efficient building design strategies to manage heat flow in buildings.

Table 2: Basic Concepts for Energy Efficient Building Design

Action	Wall	Roof	Window
Minimize conduction losses	Use insulation with low U-value	Use insulation with low U-value	Use material with low U-factor
Minimize convection losses and moisture penetration	Reduce air leakage and use	Reduce air leakage and use vapour barrier	Use prefabricated windows and seal the joints between windows and wall
Minimize radiation losses	Use light coloured coating with high reflectance	Use light coloured coating with high reflectance	Use glazing with low Solar Heat Gain Coefficient (SHGC); Use shading devices

Source: ECBC Tip Sheet- Building Envelope

The heat flow through the opaque elements of the building envelope like the walls, roof, or the floor is estimated by the thermal properties of building materials such as density, thermal conductivity, specific heat, thermal conductance, thermal resistance (R-Value) and thermal transmittance (U-Value). The thermal properties of common building materials are available in Appendix C of the ECBC.

Thermo physical properties of building materials

Density (ρ): This is defined as the ratio of the mass of the substance to the volume of the substance at atmospheric condition. Density is expressed in kg / m^3.

Thermal Conductivity (k): Thermal conductivity is the time rate of steady state heat flow through a unit area of 1 m thick homogeneous material in a direction perpendicular to isothermal planes, induced by a unit (1K) temperature difference across the sample [3]. Thermal conductivity k-value is expressed in W / m-K (Btu/ h-ft-F or Btu-in / h- ft^2- F). It is a function of material mean temperature and moisture content. Thermal conductivity is a measure of the effectiveness of a material in conducting heat.

Specific Heat (C_P): Specific heat capacity, also known as specific heat**,** is the measure of the heat energy required to increase the temperature of a unit quantity of a substance by a certain temperature interval. It is expressed in KJ / kg-K.

Thermal Conductance (C): Thermal Conductance is the rate of heat flow through a unit surface area of a component with unit (1 K) temperature difference between the surfaces of the two sides of the component. It is the reciprocal of the sum of the resistances of all layers

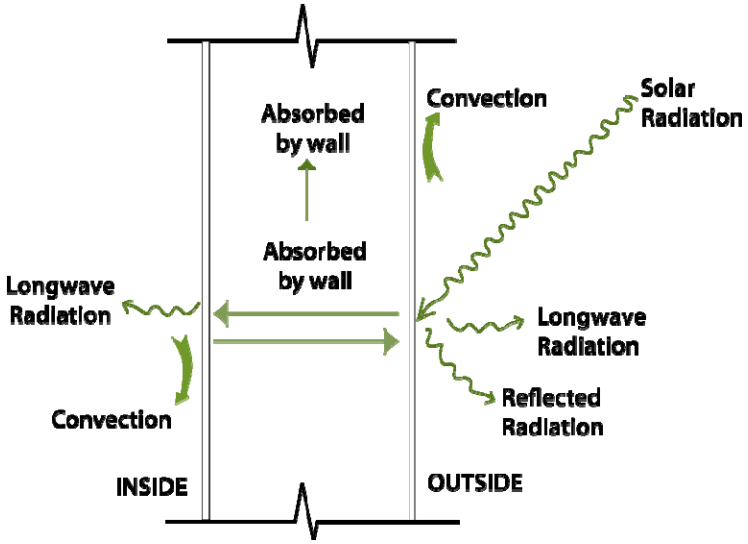
composing that component without the inside and outside air films resistances. It is similar to thermal conductivity except it refers to a particular thickness of material. Thermal conductance, C-value, is expressed in W/m²-K (Btu/ h-ft²-F)

Thermal Resistance (R): Thermal resistance of insulation is a measure of the effectiveness of thermal insulation to retard the heat flow. It is a function of material thermal conductivity, thickness and density. A material with high thermal resistivity (low thermal conductivity) is an effective insulator. Thermal resistance R-value is expressed in m²- K / W (h-ft²-F / Btu).

Thermal Transmittance (U): Thermal transmittance is a rate of heat flow through a unit surface area of a component with unit (1K) temperature difference between the surfaces of the two sides of the component. It is the reciprocal of the sum of the resistances of all layers composing that component plus the inside and outside air film resistances. It is often called the Overall Heat Transfer Coefficient, U-value, and is expressed in W / m²-K (Btu/ F-ft²-h)

Example 2: Heat Transfer Processes Occurring in a Wall

Consider a wall having one surface exposed to solar radiation and the other surface facing a room. Of the total solar radiation incident on the outer surface of the wall, a part of it is reflected to the environment. The remaining part is absorbed by the wall and converted into heat energy. A part of the heat is again lost to the environment through convection and radiation from the wall's outer surface. The remaining part is conducted into the wall; where it is partly stored thereby raising the wall temperature, while the rest reaches the room's interior surface. The inner surface transfers heat by convection and radiation to the room air, raising its temperature. Heat exchanges like these take place through opaque building elements such as walls and roofs. Additionally, mutual radiation exchanges between the inner surfaces of the building also occur (for example, between walls, or between a wall and roof). Such heat transfer processes affect the indoor temperature of a room and consequently, the thermal comfort experienced by its occupants.



Source: Nayak & Prajapati (2006). Handbook On Energy Conscious Buildings.

ECBC Compliance

The ECBC building envelope requirements are based on the climate zone in which the building is located. ECBC defines five climate zones (hot-dry; warm-humid; composite; temperate; cold), which are distinctly unique in their weather profiles (Appendix E). Based on the characteristics of climate, the thermal comfort requirements in buildings and their physical manifestation in architectural form are also different for each climate zone. (See below Table 3) These physical manifestations, in turn, dictates the ECBC requirements for the envelope, as well as other building components that are applicable to the building.

Table 3: Comfort Requirements and Physical Manifestations in Buildings

HOT AND DRY CLIMATE ZONE	
Thermal Requirements	Physical Manifestation
Resist Heat Gain	
Decrease exposed surface area	Orientation and shape of building
Increase thermal resistance	Insulation of building envelope
Increase thermal capacity (Time lag)	Massive structure
Increase buffer spaces	Air locks/ lobbies/balconies/verandahs
Decrease air exchange rate (ventilation during day-time)	Weather stripping and scheduling air changes
Increase shading	External surfaces protected by overhangs, fins and trees
Increase surface reflectivity	Pale colour, glazed china mosaic tiles etc.
Promote Heat Loss	
Ventilation of appliances	Provide windows/ exhausts
Increase air exchange rate (Ventilation during night-time)	Courtyards/ wind towers/ arrangement of openings
Increase humidity levels	Trees, water ponds, evaporative cooling
WARM AND HUMID CLIMATE ZONE	
Thermal Requirements	Physical Manifestation
Resist Heat Gain	
Decrease exposed surface area	Orientation and shape of building
Increase thermal resistance	Roof insulation and wall insulation
	Reflective surface of roof
Increase buffer spaces	Balconies and verandas
Increase shading	Walls, glass surfaces protected by overhangs, fins and trees
Increase surface reflectivity	Pale colour, glazed china mosaic tiles, etc.
Promote Heat Loss	
Ventilation of appliances	Provide windows/ exhausts
Increase air exchange rate (Ventilation throughout the day)	Ventilated roof construction. Courtyards, wind towers and arrangement of openings
Decrease humidity levels	Dehumidifiers/ desiccant cooling
MODERATE CLIMATE ZONE	
Thermal Requirements	Physical Manifestation
Resist Heat Gain	
Decrease exposed surface area g	Orientation and shape of building

Increase thermal resistance	Roof insulation and east and west wall insulation
Increase shading	East and west walls, glass surfaces protected by overhangs, fins and trees
Increase surface reflectivity	Pale colour, glazed china mosaic tiles, etc.
Promote Heat Loss	
Ventilation of appliances Provide windows/ exhausts	Provide windows/ exhausts
Increase air exchange rate (Ventilation)	Courtyards and arrangement of openings
COLD (Cloudy/Sunny) CLIMATE ZONE	
Thermal Requirements	Physical Manifestation
Resist Heat Loss	
Decrease exposed surface area	Orientation and shape of building. Use of trees as wind barriers
Increase thermal resistance	Roof insulation, wall insulation and double glazing
Increase thermal capacity (Time lag)	Thicker walls
Increase buffer spaces	Air locks/ Lobbies
Decrease air exchange rate	Weather stripping
Increase surface absorptive	Darker colours
PROMOTE HEAT GAIN	
Reduce shading	Walls and glass surfaces
Utilize heat from appliances	
Trapping heat	Sun spaces/ green houses/ Trombe walls etc.
COMPOSITE CLIMATE ZONE	
Thermal Requirements	Physical Manifestation
Resist Heat Gain in Summer and Resist Heat Loss in Winter	
Decrease exposed surface area	Orientation and shape of building. Use of trees as wind barriers
Increase thermal resistance	Roof insulation and wall insulation
Increase thermal capacity (Time lag)	Thicker walls
Increase buffer spaces	Air locks/ Balconies
Decrease air exchange rate	Weather stripping
Increase shading	Walls, glass surfaces protected by overhangs, fins and trees
Increase surface reflectivity	Pale colour, glazed china mosaic tiles, etc.
Promote Heat Loss in Summer/ Monsoon	
Ventilation of appliances	Provide exhausts
Increase air exchange rate (Ventilation)	Courtyards/ wind towers/ arrangement of openings
Increase humidity levels in dry summer	Trees and water ponds for evaporative cooling
Decrease humidity in monsoon	Dehumidifiers/ desiccant cooling

Source: Nayak and Prajapati (2006). Handbook On Energy Conscious Buildings

Compliance Approaches

After establishing the specific climate zone in which the building is located, determine which compliance approach is the best fit for your design. The ECBC allows the following approaches:

1. **Prescriptive Approach:**

   This is a standard component-based approach using "look-up" tables that assign minimum thermal performance requirements (U-Values, R-Values, SGHC etc.) for each element (roofs, opaque walls, vertical fenestration, and skylights) based on five different climate zones. This approach is quick and easy to use, but this approach is somewhat restrictive because requirements have to be met exactly as specified.

   The prescriptive requirements for insulating levels of opaque components such as roofs and walls are based on each of the five climate zones in terms of a maximum U-factor or a minimum R-value for 24 hour use buildings & 8-hrs day time use buildings. With the prescriptive option, each envelope component must separately satisfy the requirements of the Code. This is the simplest of all the compliance options. If insulation is installed that has the prescribed R-value, then there is no need to demonstrate compliance with the thermal performance (U-factor) of the construction assembly. When using the maximum U-factor criteria, ECBC Section 11: Appendix C contains defaulted U-factors for most constructions so that the user rarely has to calculate a U-factor to show compliance.

   Prescriptive design criteria are also provided for fenestration (windows, glass doors, and skylights). The fenestration criteria depend on the window-to wall ratio (in the case of windows) and the skylight-roof ratio (in the case of skylights). Window-wall ratio (WWR) is limited to 60% of the gross exterior wall and the skylight-roof ratio is limited to 5% of the roof area. Fenestration criteria are expressed in terms of maximum solar heat gain coefficient (SHGC) and maximum U-factor. Visible light transmission (VLT) is also prescribed for different values of WWR.

   Requirements for Alterations to Building Envelope

   Follow the prescriptive requirements for fenestration, insulation, and air leakage as applicable to the portion of the envelope being altered.

   Do not show compliance with envelope requirements for the following types of envelope alterations (which do not increase building energy use):

   • Replacement of glass in an existing sash and frame (the U-factor and SHGC of the replacement glazing must be equal to or lower than the existing glazing)

   • Modifications to roof/ceiling, wall, or floor cavities (these must be insulated to full depth with insulation) and

   - Modifications to walls and floors that do not have cavities and where no new cavities are created

2. **Envelope Trade-Off Approach**:

   This is a systems based approach, where the thermal performance of individual envelope components can be reduced if compensated by higher efficiency in other building systems or components (i.e., using higher wall insulation could allow for a less stringent U-value requirement for windows, or vice versa.) These trade-offs typically occur within major building systems – envelope, lighting, or mechanical.

   This method offers the designer more flexibility than strictly following the prescribed values for individual elements. The thermal performance of one envelope component such as the roof can fail to meet the prescriptive requirements as long as other components perform better than what is required. Trade-offs are permitted only between building envelope components. It is not possible, for instance, to make trade-offs against improvements in the lighting or HVAC systems. However, this makes using the envelope trade-off option more complicated than the prescriptive method. It is necessary to calculate the surface area of each exterior and semi-exterior surface; all areas must also be calculated separately for each orientation. The equations used for calculating envelope

performance factor under envelope trade-offs are documented in ECBC Section 12: Appendix D.

3. **Whole Building Performance Approach:**

   This is a compliance method that takes into consideration the overall energy performance of the proposed building design. This method compares a proposed design with a standard or the base case criteria for design, through the use of computer simulation. Compliance is achieved is the simulation demonstrates that the proposed design is at least as energy efficient as the baseline in terms of annual energy use. This approach allows great flexibility but requires considerably more effort. Tradeoffs can be made between the building envelope and the lighting and/or mechanical systems. The 'base case criteria' is described in detail in Appendix B of the ECBC. A building complies with the whole building performance method when the estimated annual energy use of the proposed design is less than the standard design, even though it may not comply with all the prescriptive requirements specified in Section 4 through 8 of ECBC.

4.2 MANDATORY REQUIREMENTS

Regardless of which compliance path is taken, all building envelope designs must comply with several mandatory provisions. These requirements relate to fenestration, opaque construction, and envelope sealing.

4.2.1 Fenestration

Glazing products or fenestration, (windows, doors, and skylights) can be specified to reduce solar heat gain and control light levels and glare. Heat transfer and energy losses occur through fenestration by conduction, convection, and long wave infra-red radiation (See Figure 6).

For heat flow through fenestration, apart from the minimum U-factor or thermal transmittance, the Solar Heat Gain Coefficient (SHGC), Minimum Visible Transmission (VLT or VT) and the maximum window to wall ratio (WWR) are taken into consideration.

Window to Wall Ratio (WWR) is the proportion of window area compared to the gross wall area. Gross exterior wall area is measured horizontally from the exterior surface; it is measured vertically from the top of the floor to the bottom of the roof.

4.2.1.1 U-Factors

U-Value = (1/R-value). Clear glass, which is the most common type of glass used today, has no significant thermal resistance (R-value) from the pane itself; however, it has a value of R-0.9 to R-1.0 due to the thin films of air on the interior and exterior surfaces of the glass. The R-value, and U-factor (thermal transmittance), must account for the entire fenestration construction including the effects of the frame, the spacers in double glazed assemblies, and the glazing. There are a wide variety of materials, systems, and techniques used to manufacture fenestration products, and accurately accounting for these factors is of utmost importance when meeting the fenestration requirements.

U- values for fenestration products (including the sash and frame) are required to be determined in accordance with ISO- 15099 (as specified in ECBC Section 11:Appendix C) by an accredited independently laboratory and labeled and certified by the manufacturer or other responsible party. In the U.S, the fenestration U-values are determined in accordance with the National Fenestration Rating Council (NFRC) Standard 100. NFRC is a membership organization of window manufacturers, researchers, and others that develops, supports, and maintains fenestration rating and labeling procedures. Most fenestration manufacturers have their products rated and labeled through the NFRC program. Certified products receive an 8 ½ by 11 inch NFRC label that lists the U-factor, SHGC, visible transmittance, the project address, the number of these fenestration products to be installed in the building project, the frame material supplier, the glazing material supplier, the glazing contractor, and the certification authorization.

4.2.1.2 SHGC

There is a complex relationship between these three characteristics of fenestration systems (See Figure 6). ECBC requires U-factor and Solar Heat Gain Coefficient (SHGC) to be determined for all fenestration products by the manufacturer or other responsible party [ECBC 4.2.1.1 and 4.2.1.2].

The SHGC indicates how well the product insulates against heat caused by sun falling directly on the glass. The ECBC will recommend the SHGC and U-Value you should have for your specific Climate Zone. Lower SHGC is appropriate for hot climates to avoid added heat gain, while colder climates have higher SHGC requirements. Default values are available in Appendix C of the code.

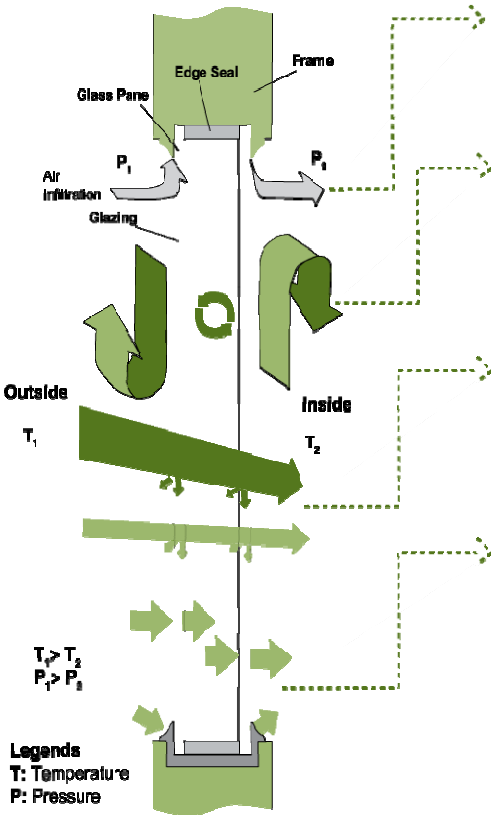
The *Solar Heat Gain Coefficient* (SHGC) is the ratio of the solar heat gain entering the space through the fenestration area to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which then enters the space through radiation, conduction, or convection. In hot climates, SHGC is the most important performance characteristic of fenestration, more important than the U-factor. With a lower number, less sunlight and heat can pass through the glazing. The SHGC is based on the properties of the glazing material, the number of panes of glass in the window, and the window operation (either operable or fixed). Glazing units with a low SHGC will help reduce the air conditioning energy use during the cooling season. The ECBC requires that SHGC be determined in accordance with ISO- 15099 by an accredited independent laboratory, and labeled and certified by the manufacturer or other responsible party. SHGC has replaced the shading coefficient (SC) as the figure of merit for solar heat gain through fenestration products. SC does not account for the fenestration frame and is determined for the center-of-glass. Furthermore, SC is relative to ⅛ in. (3 mm) clear glass, whereas SHGC is relative to a perfectly transmitting glazing material. When SC is available, SHGC is established as 0.86 times the SC.

But these recommendations do not take into account daylighting and the effect that Visible Light Transmission (VLT) can have on the performance of the overall structure during the heat/cool/light cycles. VLT is the amount of solar radiation in the visible spectrum that passes through fenestration. Products with low SHGC generally have a low VLT; however, if the VLT is too low, the view from inside the building will be impaired. If you lower VLT too much, the daylighting in the interior will be reduced to a level that may require supplemental electrical lighting for some functions, or to make the environment enjoyable to the occupants. Thus, for buildings with lower window to wall ratios (WWR), higher VLT fenestration systems are permitted under the code. The ECBC mandates that the vertical fenestration product shall have the minimum Visual Light Transmittance (VLT) as an inverse function of Window Wall Ratio (WWR) under ECBC Section 4.3.3.1.

4.2.1.3 Air Leakage

Air leakage for glazed swinging entrance doors and revolving doors shall not exceed 5.0 l/s-m^2. Air leakage for other fenestration and doors shall not exceed 2.0 l/s-m^2.

Figure 6: Heat and Air Movement through Double Glazing Window System



Infiltration

Air leaks around the frame, around the sash, and through gaps in movable window parts. Infiltration is foiled by careful design and installation, weather-stripping and caulking (type of sealing).

Convection

Convection takes place in gas. Pockets of high temperature, low-density gas rises setting up a circular movement pattern. Convection occurs within multiple-layer windows and on either side of window. Optimally spacing gas-filled gaps minimizes combined conduction and convention.

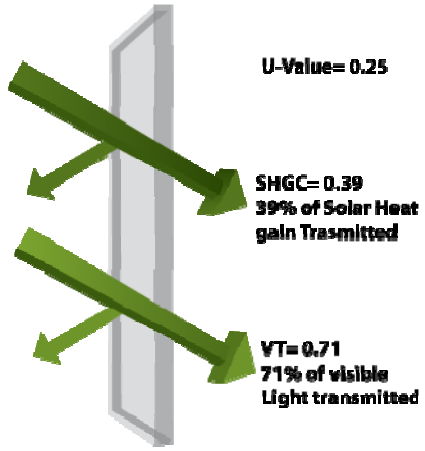
Radiation

Radiation is the energy that passes directly through air from a warmer surface to a cooler one. Radiation is controlled through low-emissivity films or coatings. SHGC determines the amount of radiation that can pass through glazing.

Conduction

Conduction occurs as adjacent molecules of gas or solids pass thermal energy between them. Conduction is minimized by adding layers to trap air spaces, and putting low conductivity (Argon or Krypton) gases in those spaces. Frame conductivity is reduced by using low-conductivity material such as vinyl or

Figure 7: Example of U-Value, SHGC and VT

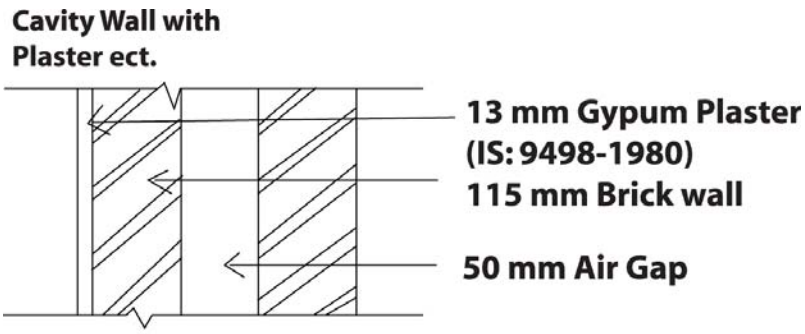


4.2.2 Opaque Construction

For ECBC compliance purposes it is important to determine the overall steady state rate at which heat flows through architectural envelope elements. This is provided by the U-Value or the thermal transmittance. The U-Values are calculated for particular elements (walls, roofs, etc) by finding the thermal resistances (R-Values) of each component materials, including air layers and internal air spaces, then adding all the resistances to obtain ∑R. The U-Value is the reciprocal of this sum of resistances (U-Value = 1 / ∑R)

A U-factor is also required for opaque constructions; default values are provided in Section 11: Appendix C of the code [ECBC 4.2.2]. The U-factor demonstrates insulating capacity and will be used to determine compliance under ECBC sections 4.3.1 and 4.3.2.

Example 3: Procedure for determining the U-Value for a composite wall assembly (Cavity Wall with Plaster)



Layer 1: 13 mm Gypsum Plaster; Thickness (L1) = 0.013 m; Resistance for Layer 1 (R1) = 0.056 Km^2/W

Layer 2:115 mm brick wall;

L2 = 0.115 m; Conductivity for Layer 2 (k2) = Range of 0.81-0.98 W/m-K;

Thus, Resistance for Layer 2 (R2) can be calculated as follows:-

R2=L2*1/k2 = 0.115 * (1.24-1.02)

= Range of 0.1426 - 1173 Km^2/W

Layer 3:50 mm air gap;

L3= 0.05m; k3 =0.0352 W/m-K ; R3=L3*1/k3 = 1.4 Km^2/W

Layer 4: 115 mm brick wall;

L4 = 0.115 m; k4 =Range of 0.81-0.98 W/m-K

R4=L4*1/k4 = 0.115* (1.24-1.02)

= Range of 0.1426 - 1173 Km2/W

Minimum R-Value for the composite wall

R1+ R2+ R3 + R4 = 0.056 + 0.1426 + 1.4 + 0.1426

= 1.7412 Km^2/W

Minimum U-Value for the composite wall = 1/R

= 1 /1.7412

= 0.57 W/m^2K

NOTE:

Values for conductivity (K) and R-Values for brick wall (1920 kg/m^3 density) and 13 mm lightweight aggregate gypsum plaster taken from ECBC Appendix C for thermal properties. Thermal properties of 50 mm air gap are given as k =0.0352 W/m-K for this example.

For simplicity, this example does not consider the resistivity of the air film at the interior and exterior surfaces of the composite wall system. The R-value of the inside and outside air films will also contribute to the total resistance of the wall system.

4.2.3 Building Envelope Sealing

Air leakage is the passage of air through a building envelope, wall, window, joint, etc. Leakage to the interior is referred to as ***infiltration*** and leakage to the exterior is referred to as ***exfiltration***. Excessive air movement significantly reduces the thermal integrity and performance of the envelope and is, therefore, a major contributor to energy consumption in a building.

A tightly constructed building envelope is largely achieved through careful construction practices and attention to detail. Building envelopes should be carefully designed to limit the uncontrolled entry of outdoor air into the building. Air leakage introduces sensible heat into conditioned spaces. In climates with moist outdoor conditions, it is also a major source of latent heat. Latent heat must be removed by the air-conditioning system at considerable expense.

In addition to causing energy loss, excessive air leakage can cause condensation to form within and on walls. This can create many problems including reducing insulation R-value, permanently damaging insulation, and seriously degrading materials. It can rot wood, corrode metals, stain brick or concrete surfaces, and in extreme cases cause concrete to spall, bricks to separate, mortar to crumble and sections of a wall to fall jeopardizing the safety of occupants. It can corrode structural steel, re-bar, and metal hangars and bolts with very serious safety and maintenance issues. Moisture accumulation in building materials can lead to the formation of mold that may require extensive remediation.

Virtually anywhere in the building envelope where there is a joint, junction or opening, there is potential for air leakage. Air leakage will cause the HVAC system to run more often and longer at one time, and still leave the building uncomfortable for its occupants.

All openings in the building envelope, including joints and other openings that are potential sources of air leakage, are required to be sealed to minimize air leakage [ECBC 4.2.3]. It means that all gaps between wall panels, around doors, and other construction joints must be well-sealed. Ceiling joints, lighting fixtures, plumbing openings, doors, and windows should all be considered as potential sources of unnecessary energy loss due to air infiltration.

Specifically, the code requires the following areas of the enclosed building envelope to be sealed, caulked, gasketed, or weather-stripped to minimize air leakage:

- Joints around fenestration and door frames
- Openings between walls and foundations and between walls and roof and wall panels

- Openings at penetrations of utility services through, roofs, walls, and floors
- Site-built fenestration and doors
- Building assemblies used as ducts or plenums
- All other openings in the building envelope.

The Code specifies air leakage for glazed swinging entrance doors and revolving doors shall not exceed 5.0 l/s-m2. Air leakage for other fenestration and doors shall not exceed 2.0 l/s-m2. As with all of the mandatory requirements, the air leakage requirements must be met with all compliance approaches, even the Whole Building Performance method.

4.3 PRESCRIPTIVE REQUIREMENTS

For this component-based compliance approach, ECBC sets requirements for:

- Exterior Roofs and Ceilings,
- Opaque walls,
- Vertical fenestration, and
- Skylights.

Roofs and opaque walls can either meet maximum U-factors for assemblies or minimum R-factors for the insulation only [ECBC 4.3.1 and 4.3.2]. The requirements are climate-based and different for buildings used only during the day, such as offices, from those used 24-hours, such as hospitals. ECBC Appendix D provides values for typical constructions. If designing a cool roof, requirements for minimum solar reflectance and initial emittance levels are specified [ECBC 4.3.1.1].

Maximum U-factors and SHGCs are provided for all vertical fenestration based on climate; however, there are modifications allowed to the SHGC limits when using overhangs or fins, and in the case of windows located over 2.2 meters from the floor [ECBC 4.3.3].

Vertical fenestration is also required to meet minimum levels of visual light transmittance (VLT) to facilitate use of daylighting [ECBC 4.3.3.1]. Similarly, skylights have U-factor and SHGC maximum levels determined by ECBC and are also limited to 5 percent of the gross roof area [ECBC 4.3.4].

4.3.1 Roofs

Exterior roofs or ceilings (See Table 4) can meet the prescriptive requirements in one of two ways:

- Use the required R-value of the insulation (this R-value does not apply to building materials or air film. It should be referred exclusively for insulation), or
- Use a roof assembly U-factor that meets the maximum U-factor criterion for thermal performance (see Table 4.3.1). The U-factor takes into account all elements or layers in the construction assembly, including the sheathing, interior finishes, and air gaps, as well as exterior and interior air films.

ECBC Table 4.1 (reproduced below in

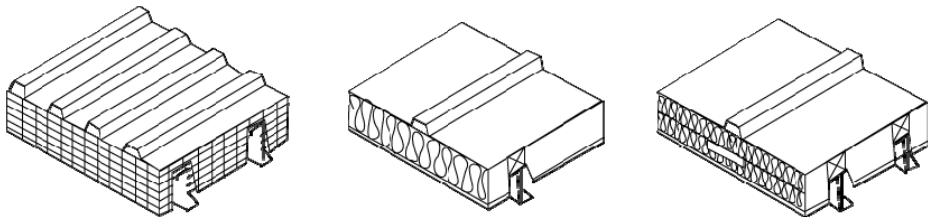
- Table 4) provides the maximum limits of the U-factor and minimum limits of R-Values for 24 hrs use buildings and daytime use buildings.

Table 4: Roof Assembly U-Factor and Insulation R-Value Requirements

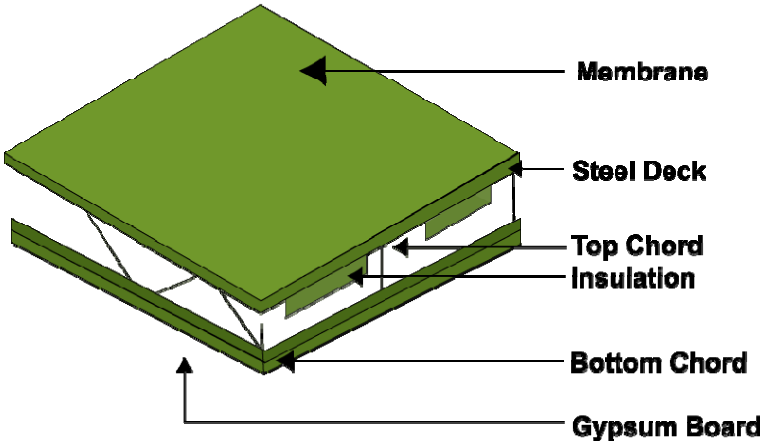
Climate Zone	24-Hour use buildings Hospitals, Hotels, Call Centers etc.		Daytime use buildings Other Building Types	
	Maximum U-factor of the overall assembly (W/m^2-°C)	Minimum R-value of insulation alone (m^2-°C/W)	Maximum U-factor of the overall assembly (W/m^2-°C)	Minimum R-value of insulation alone (m^2-°C/W)
Composite	U-0.261	R-3.5	U-0.409	R-2.1
Hot and Dry	U-0.261	R-3.5	U-0.409	R-2.1
Warm and Humid	U-0.261	R-3.5	U-0.409	R-2.1
Moderate	U-0.409	R-2.1	U-0.409	R-2.1
Cold	U-0.261	R-3.5	U-0.409	R-2.1

NOTE: The ECBC prohibits insulation from being installed directly over suspended ceilings.

Figure 8: Building Roofs

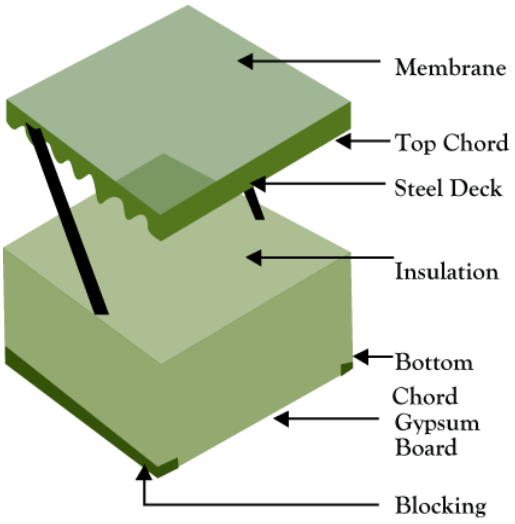


Pre-Fabricated Metal roofs showing Thermal Blocking of Purlins

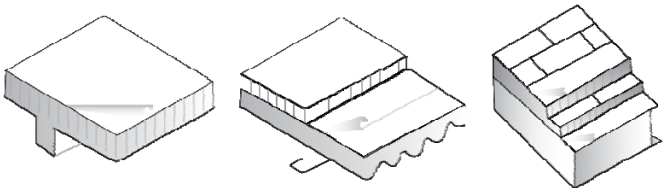


Steel Joist Roof with Insulated Cavities

Metal Framed Ceiling Insulation



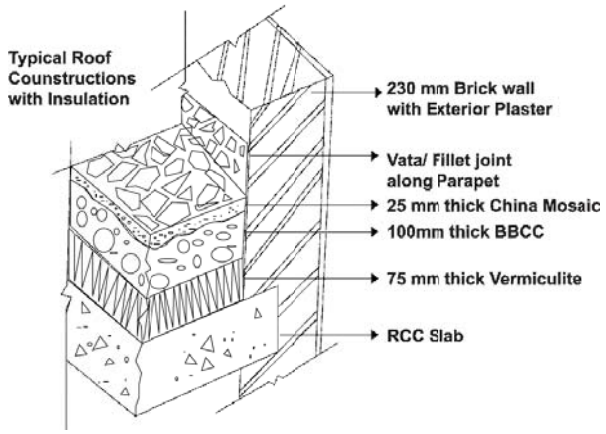
Steel Joist roof with Continuous Insulation



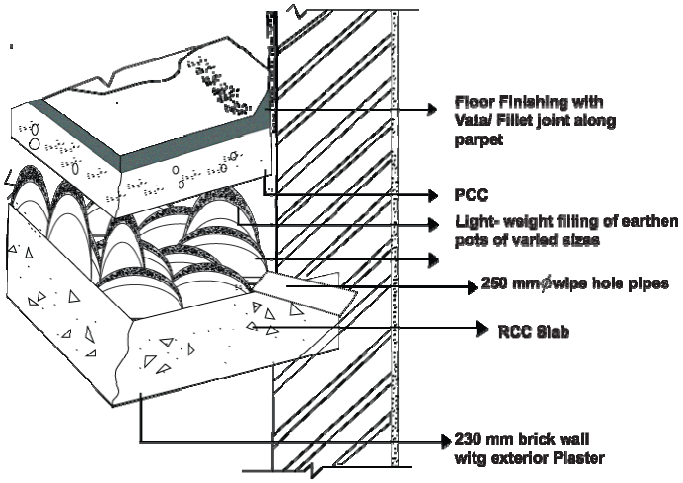
Insulation entirely above deck: Insulation is installed above a (a) concrete, (b) wood or (c) metal deck in a continuous manner. (a), (b), and (c) are shown sequentially right to left.

Figure 9: Typical Insulation Techniques for RCC Roof Construction

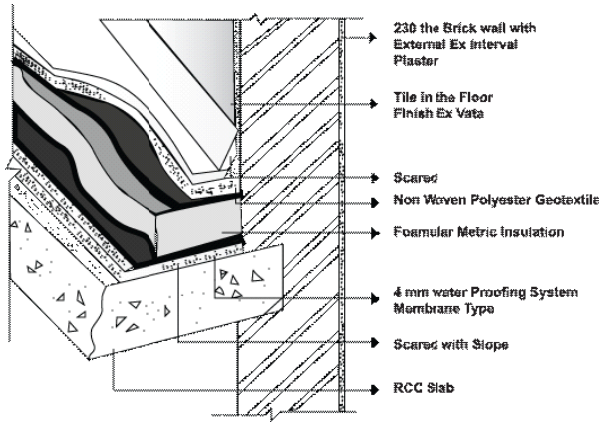
A. RCC Slab Insulated with Vermiculite



B. RCC Slab Insulated with Earthen Pots



C. RCC Slab Insulated using Foamular Metric



4.3.1.1 Cool Roofs

Depending on the material and construction, a roof will have different properties that determine how it conducts heat to the inside of the building. Cool roods are roofs covered with a reflective coating that has a high emissivity property (the characteristic of emitting infrared energy) that is very effective in reflecting the sun's energy away from the roof surface. . These "cool roofs" stay 10 to 16 degrees C cooler than a normal roof under a hot summer sun; this quality greatly reduces heat gain inside the building and the cooling load that needs to be met by the HVAC system.

In hot climates, cool roofs (or, high emittance roof surfaces) are an effective way to reduce solar gains and cut building owners' energy costs. Because cool roofs gain less heat than normal roofs, they reduce the need for air conditioning and make buildings more comfortable to the people inside. The light color reflects sunlight and heat away from the building, and the high emittance allows heat to escape to the atmosphere when the surface becomes heated. Although some surfaces, such as galvanized metal, have a high reflectance, they have a low emittance. These surfaces reflect heat, but heat that is absorbed cannot escape. Other surfaces, such as dark paint, have a high emittance but a low reflectance. These surfaces allow heat to escape, but do a poor job of reflecting heat that strikes the surface.

Most cool roof materials for low-sloped roofs are white or another light color. For steep-sloped roofs that are often visible from the ground, roofing material manufacturers have developed popular roof colors other than white that will still reflect or emit the sun's energy away from the building.

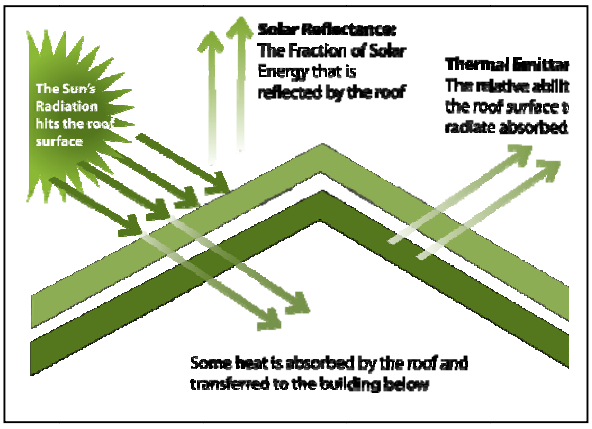
In accordance with **ECBC Section 4.3.1.1**, roofs with slopes less than 20 degrees shall have an initial solar reflectance of no less than 0.70 and an initial emittance no less than 0.75. Solar reflectance shall be determined in accordance with ASTM E903-96 and emittance shall be determined in accordance with ASTM E408-71 (RA 1996).

Cool roofs have other benefits in addition to reducing operating costs. For building owners, they can cut maintenance costs and increase the life expectancy of the roof. For society in general, cool roofs can even help to reduce the urban heat island effect that makes our cities hotter and produces unhealthy air.

FAQs 1: Cool Roofs

What is a Cool Roof?

Cool roofs are highly reflective and emissive materials that stay 10 to 16 degrees C cooler in the sun, thereby reducing energy costs, improving occupant comfort, cutting maintenance costs, increasing the life cycle of the roof, and contributing to the reduction of urban heat islands and associated smog. Reflectance (albedo) is measured on a scale of 0 to 1, with 0 being for a perfect absorber and 1 being a perfect reflector. An ideal exterior surface coating for a hot climate would have a reflectance of near 1.0, absorptance of near 0, and infrared emissivity near 1.0 to radiate absorbed heat back to the sky.



What is meant by Urban Heat Island effect?

An Urban Heat Island is a metropolitan urban area, which is significantly warmer than its surroundings. As population centers grow in size, they tend to have a corresponding increase in average temperature. Scientists refer to this phenomenon as the "Urban Heat Island Effect" (UHIE). The two main causes of the

urban heat island is modification of the land surface by urban development and waste heat generated by energy usage. One consequence of urban heat islands is the increased energy required for air conditioning and refrigeration in cities that are in comparatively hot climates.

What types of roofing products are available for commercial and residential applications?

Products for low-slope roofs, found on commercial and industrial buildings fall into two categories: single-ply materials and coatings. Single-ply materials are large sheets of pre-made roofing that are mechanically fastened over the existing roof and sealed at the seams. Coatings are applied using rollers, sprays, or brushes, over an existing clean, leak-free roof surface. Products for sloped roofs are currently available in clay, or concrete tiles. These products stay cooler by the use of special pigments that reflect the sun's infrared heat.

How cool is a Cool Roof?

During the summer, a typical dark roof has a surface temperature of 65 to 88°C at peak, while cool roofs peak surface temperature remains between 38°C to 40°C.

Do Cool Roofs cost more than conventional roofs?

Research shows that the cost of a cool roof compared to a traditional roof can be the same or slightly higher per square foot for the cool roof. One analysis showed cool roofs to be cost-effective over the life cycle of the roofing material. Cool protective coatings can be reapplied repeatedly every 10 to 15 years and reduce, if not eliminate the need for expensive roof tear-offs. Combining these maintenance savings with an average 20 percent savings on air conditioning costs make cool roofing a better bargain over the long term.

Technical Tips for Cool Roofs:

Use of solar reflective urban surfaces and planting of urban trees are inexpensive measures that can reduce summertime temperatures.

(Image Source: McGraw_Hill Construction (2007); Sustainable Roofing Strategies . Available from http://www.construction.com/CE/articles/0707roofing-3.asp)

Interesting Fact related to Cool Roof implementation

(Source-Akbari, H., S. Menon, and A. Rosenfeld. 2008. "Global cooling: increasing solar reflectance of urban areas to offset CO2,")

Most existing flat roofs are dark and reflect only 10 to 20% of sunlight. Resurfacing the roof with a white material that has a long-term solar reflectance of 0.60 or more increases its solar reflectance by at least 0.40. Akbari *et al.* estimate that so retrofitting 100 m^2 (1000 ft^2) of roof offsets 10 tons of CO_2 emission. (For comparison purposes, we point out that a typical US house emits about 10 tons of CO_2 per year.) Emitted CO_2 is currently traded in Europe at about $25/ton, making this 10-ton offset worth $250.

It is fairly easy to persuade (or to require) the owners of buildings to select white materials for flat roofs, and in California this has been required since 2005. However, the demand for white *sloped* roofs is limited in North America, so California compromises by requiring only "cool colored" surfaces for sloped roofs. (This rule takes effect in July 2009.) Use of cool-colored surfaces increases solar reflectance by about 0.20 and yields a CO_2 offset of about five tons per 100 m^2, or about half that achieved with white surfaces. The solar reflectance of pavement can be raised on average by about 0.15, offsetting about four tons of CO_2 per 100 m^2.

Over 50% of the world population now lives in urban areas, and by 2040 that fraction is expected to reach 70%. Pavements and roofs comprise over 60% of urban surfaces (roofs 20 to 25%, pavements about 40%). Akbari *et al.* estimate that permanently retrofitting urban roofs and pavements in the tropical and temperate regions of the world with solar-reflective materials would offset 44 billion tons of emitted CO_2, worth $1.1 trillion at $25/tonne.

How can the reader visualize this *one time* offset of 44 billion tons of CO_2? The average car emits about 4 tons of CO_2 each year. Permanently increasing the solar reflectance of urban roofs and pavements worldwide would offset 11 billion car-years of emission. This is equivalent to taking the world's approximately 600 million cars off the road for 18 years.

Equivalent Car Offsets from Cool Roofs

Duration of Program	Annual CO_2 Offsets	Equivalent Cars Offset
10 Yr	2.4 Billion t/yr	600 million Cars for 10 years
20 Yr	1.2 Billion t/yr	300 Million Cars for 20 years

If roofs were changed from their current dark colors to white for flat roofs and cool colors for sloped roofs, we could offset 24 billion tons of CO_2. If we take 20 years to implement just the cool roofs portion, it's the equivalent of taking half of the cars in the world off the road for every year of the 20 year program (see table). The offset provided by cooling urban surfaces affords us a significant delay in climate change during which we can take further measures to improve energy efficiency and sustainability.

4.3.2 Opaque Walls

All walls between the outdoors and conditioned space or unconditioned space must be insulated. As shown in **Error! Reference source not found.**, these include:

- Exterior walls
- Knee walls in attics

- Perimeter joists
- Walls between a conditioned space and an unconditioned space such as in a warehouse
- Skylight wells.

Opaque walls can meet the component requirements by either using a construction that has an assembly U-factor lower than the specified criteria as shown in ECBC Table 4.2 (reproduced below in Table 5), or by installing the required R-value of insulation. R-value is for the insulation alone and does not include building materials or air films.

Appendix C of the Standard has tables of default U-factors for all classes of construction. For opaque doors, the U-factor is the only compliance option.

Figure 10: Opaque Walls

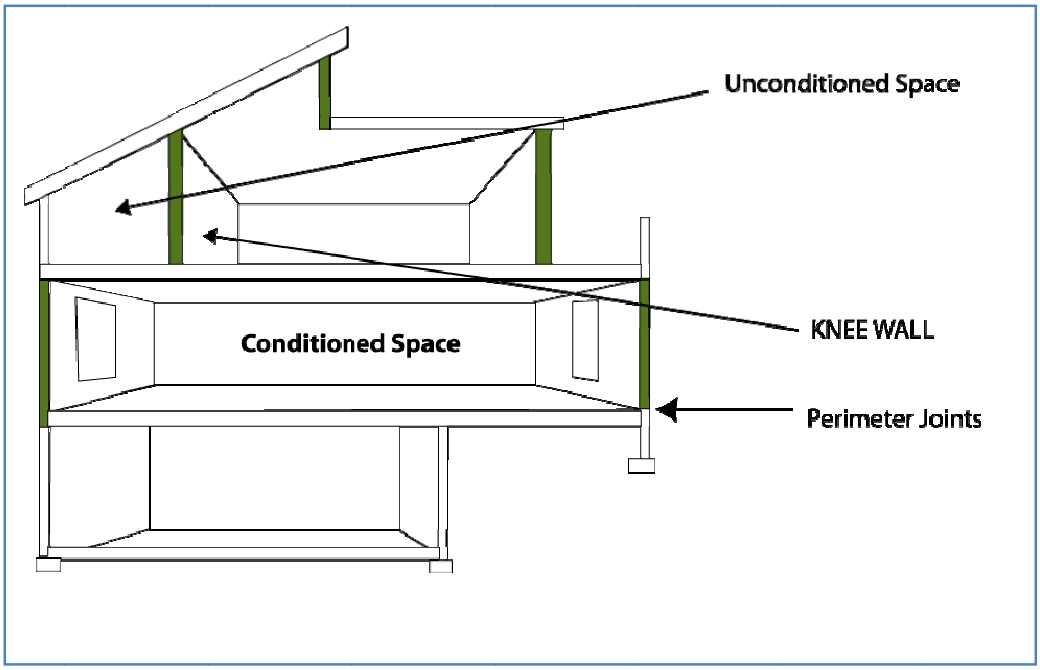
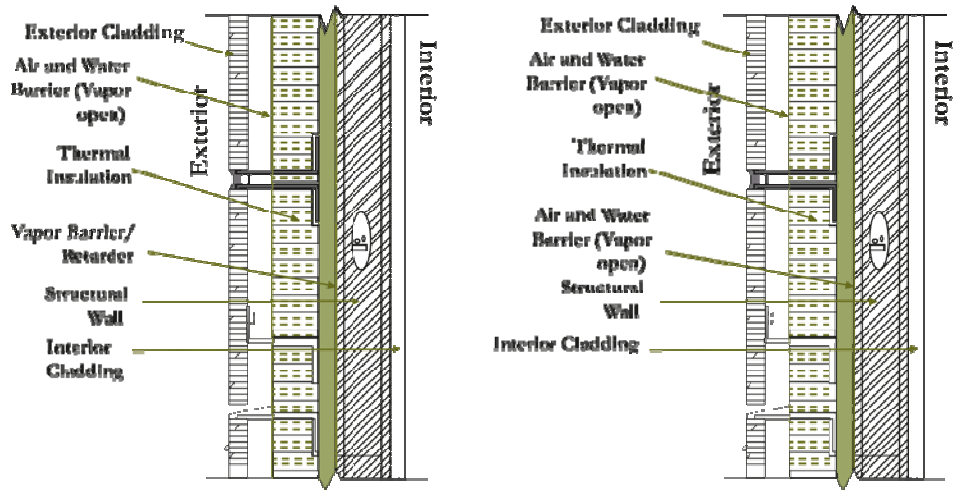


Table 5: Opaque Wall Assembly U-Factor and Insulation R-Value Requirements

Climate Zone	Hospitals, Hotels, Call Centers (24-Hour)		Other Building Types (Daytime)	
	Maximum U-factor of the overall assembly (W/m^2-°C)	Minimum R-value of insulation alone (m^2-°C/W)	Maximum U-factor of the overall assembly (W/m^2-°C)	Minimum R-value of insulation alone (m2-°C/W)
Composite	U-0.440	R-2.10	U-0.440	R-2.10
Hot and Dry	U-0.440	R-2.10	U-0.440	R-2.10
Warm and Humid	U-0.440	R-2.10	U-0.440	R-2.10
Moderate	U-0.440	R-2.10	U-0.440	R-2.10
Cold	U-0.369	R-2.20	U-0.352	R-2.35

Figure 11: Placement of Barriers



In hot, composite and humid climate zones, Vapor permeable materials which allow drying in both directions are preferable.

In cold and temperate climates or where the internal humidity and temperature is likely to be relatively higher than the outside, it must be ensured that materials that make up the envelope are progressively more Vapor permeable from the inside to the outside or are vented towards the outside, so that if the envelope components (such as insulation) get wet, they can dry themselves through Vapor diffusion.

Metal roofs with under deck fibrous insulation present unique challenges in moisture management. Since the metal sheet prevents active drying of insulation to the outside, it is recommended that on the inner side, the insulation be faced with a Vapor- open air and water barrier, to allow incidental ingress of moisture to diffuse as Vapor. The exception to this would be in installations where the interior temperature and humidity are expected to be significantly higher than those on the outside.

Source: DuPont

Correct Typical Opaque Exterior Wall Constructions

Metal-framed walls. Many commercial buildings and high-rise residential buildings require non-combustible construction; this is achieved with metal-framed walls. Often metal-framed walls are not structural and are used as infill panels in rigid framed steel or concrete buildings. The U-factor criteria are higher for metal-framed walls (compared to wood-framed walls) because the metal framing members are more conductive.

Metal building walls: Metal building walls consist of a metal building skin that is directly attached to metal framing members. The framing members are typically positioned in a horizontal direction and spaced at about 4 ft. A typical method of insulating metal buildings walls is to drape the insulation over the horizontal framing members and to compress the insulation when the metal exterior panel is installed.

Low mass walls: Low mass walls have a heat capacity (HC) greater or equal to 0.04 but less than 0.085 kWh/°C-m². (See the definition below for heat capacity.) Various heat capacity data exists for hollow unit masonry walls, solid unit masonry and concrete walls, and concrete sandwich panels.

High mass walls: These walls have an HC equal to or greater than 0.085 kWh/°C-m².

FAQs 2: Opaque Elements

What is Rigid Board Insulation?

Rigid board insulation is commonly made from fiberglass, polystyrene and polyurethane. It comes in a variety of thicknesses and has a high insulating value - approximately R-4 to R-8 per inch. This type of insulation is used for flat or low-sloping roofs, on basement walls, on exterior walls, as perimeter insulation at concrete slab edges and in cathedral ceilings. Sometimes rigid foam insulation boards are used to insulate the interior of masonry walls.

How is Rigid Board Insulation installed?

To install boards, wood-furring strips should be fastened to the wall first. These strips provide a nailing base for attaching interior finishes over the insulation. Fire safety codes require that a gypsum board finish, at least 1/2 inch thick, be placed over plastic foam insulation and attached to the wood furring strips or underlying masonry using nails or screws.

Use recommended adhesives to bond rigid foam insulation boards to the walls of an unventilated crawlspace. Because the insulation will be exposed, be sure to check the local fire codes and the flame-spread rating of the insulation product.

For exterior applications, rigid board insulation must be covered with weatherproof facing. Since below-grade exterior insulation allows a path for termites, check with local code officials to determine whether such insulation is acceptable. Leave a 6-inch gap between the insulation and any wood foundation element to provide a termite inspection area. When rigid board insulation extends above ground, protect the insulation by covering it with stucco or another suitable protective coating

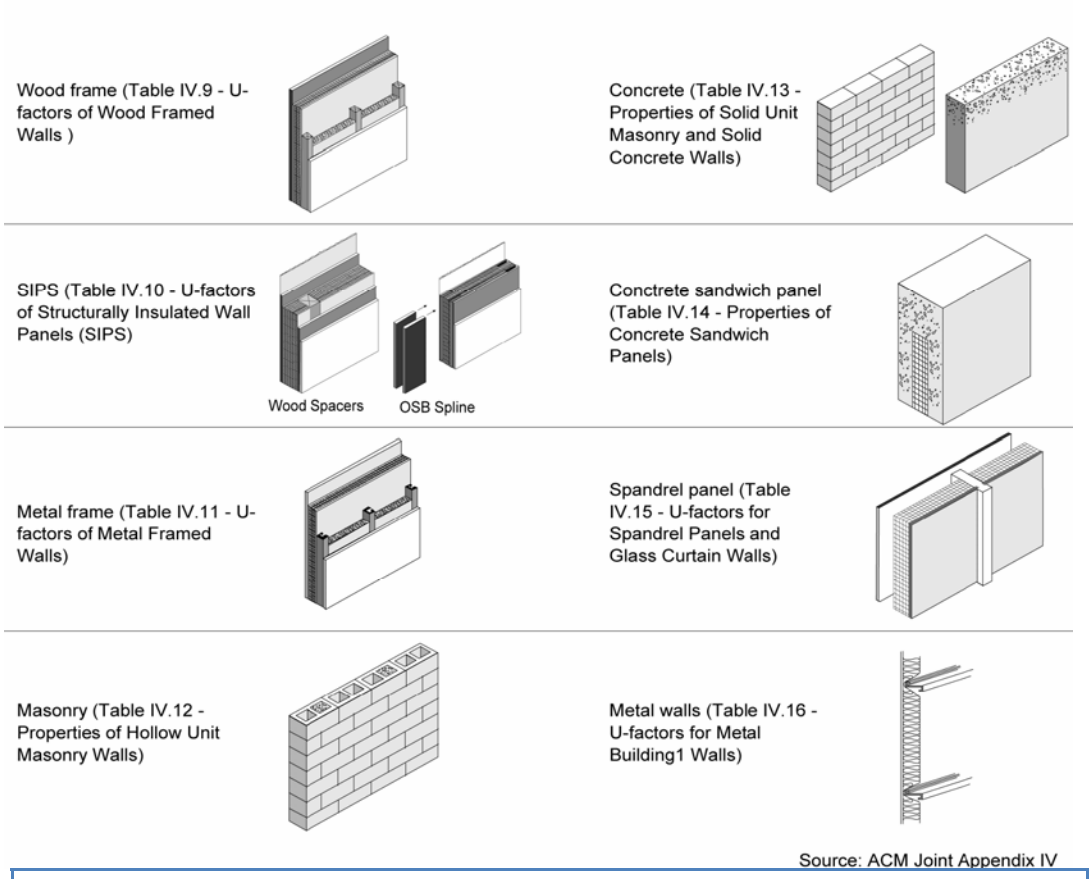
What are Structural Insulated Panels?

Structural Insulated Panels (SIPS) are an advanced method of constructing walls, roofs and floors. SIPS consist of rigid insulation (usually expanded polystyrene) sandwiched between two sheets of OSB or plywood. Little or no structural framing penetrates the insulation layer. Panels are typically manufactured at a factory and shipped to the job site in assemblies that can be as large as 8 ft by 20 ft. In the field, the SIPS panels are joined in one of two ways and the choice affects thermal performance.

What is Spray Polyurethane Foam?

Spray polyurethane foam, commonly referred to as SPF, is a spray-applied insulating foam plastic that is installed as a liquid and then expands many times its original volume. SPF formulas can be adjusted to have many different physical properties depending on the use desired. For example, the same basic raw materials can make insulation foam that is semi-rigid and soft to the touch, and also create high-density roofing foam that is resistant to foot traffic and water.

Spandrel panels and glass curtain walls


Wood frame (Table IV.9 - U-factors of Wood Framed Walls)
Concrete (Table IV.13 - Properties of Solid Unit Masonry and Solid Concrete Walls)
SIPS (Table IV.10 - U-factors of Structurally Insulated Wall Panels (SIPS)
Wood Spacers
OSB Spline
Conctrete sandwich panel (Table IV.14 - Properties of Concrete Sandwich Panels)
Metal frame (Table IV.11 - U-factors of Metal Framed Walls)
Spandrel panel (Table IV.15 - U-factors for Spandrel Panels and Glass Curtain Walls)
Masonry (Table IV.12 - Properties of Hollow Unit Masonry Walls)
Metal walls (Table IV.16 - U-factors for Metal Building1 Walls)

Source: ACM Joint Appendix IV

FAQs 3: Water migration through Opaque Elements

How does water get migrated?

Water intrusion from the exterior (rain and snow) can enter the wall in two ways: bulk water and air-transported moisture. If the wall is not allowed to dry in a reasonable amount of time, the moisture content can rise and cause rotting, mold, or mildew.

Air-transported moisture occurs when air leaks from the warm side of the wall to the cool side. Warm air holds higher amounts of water vapor than cold air. As warm air travels through a wall heading to the cold side, it will begin to cool and be forced to release moisture. This is called the dew point where condensation will occur. When there is a significant temperature drop across the wall, the dew point temperature will occur somewhere within the wall.

In the winter months in cold and moderate climate zones, the point of condensation is usually on the inside surface of the exterior sheathing. Moisture carried by airflow through the wall is deposited at the backside of the sheathing and accumulates.

In hot and humid climates, where air flow is traveling from the outside to the inside, warm moist air from the outside will be cooled on the way to the air conditioned inside, releasing moisture within the wall cavity. Air retarding wraps are a breathable membrane with microscopic pores that allow the moisture vapor to dissipate, helping to dry out a wall system and avoid damage

.

Insulation

There are many types of insulation materials available. Some materials are blown or sprayed in their application, which can provide additional air sealing benefits as described in Table 6 Different types of insulation for framed walls may be used, including:

- Fiberglass batts (R-values should be printed on the craft backing of the insulation or on the insulation itself for unfaced batts)
- Rigid foam boards (R-values should be printed on the craft backing of the insulation)
- Blown-in or sprayed insulation (the installer should provide a certification of the installed density and R-value)

Table 6: Types of Insulation for Roofs and Walls

Form	Method of Installation	Where Applicable	Advantages
Blankets: Batts or Rolls, Fiberglass, Rock wool	Fitted between studs, joists and beams. Insulation must be protected by an air barrier membrane in order to maintain the installed R-value (conductive loops & wind washing) The air barrier can be installed over exterior and/or interior sheathing and must be continuous	Unfinished walls, floors and ceilings	Easy installation, suited for standard stud and joist spacing, which is relatively free from obstructions
Loose-Fill: Spray-applied Rock wool, Fiberglass, Cellulose Polyurethane foam	Blown into place or spray applied by special equipment Insulation must be protected by an air barrier membrane in order to maintain the installed R-value (conductive loops & wind washing) The air barrier can be installed over exterior and/or interior sheathing and must be continuous	Enclosed existing wall cavities or open new wall cavities Unfinished attic floors and hard to reach places	Commonly used insulation for retrofits (adding insulation to existing finished areas) Good for irregularly shaped areas and around obstructions
Rigid Insulation: Extruded polystyrene foam (XPS), Expanded polystyrene Foam (EPS or Bead board), Polyurethane foam, Polyisocyanurate foam	Interior applications: Must be covered with ½-inch gypsum board or other building-code approved material for fire safety Exterior applications: Must be covered with weather-proof facing or continuous Air and Weather Resistive Barrier (WRB)	Basement walls, Exterior walls under finishing (Some foam boards include a foil facing, which will act as a vapor retarder. Additionally, some insulation materials- e.g. XPS and closed cells polyurethane foams– are vapor retarders. Please read the discussion about where to place, or not to place a vapor retarder) Unvented low slope roofs	High insulating value for relatively little thickness Can block thermal short circuits when installed continuously over frames or joists
Reflective Systems: Foil-faced paper, Foil-faced polyethylene bubbles, Foil-faced plastic film, Foil-faced cardboard	Foils, films, or papers: Fitted between wood-frame studs joists, and beams	Unfinished ceilings, walls, and floors (for wall applications, must consider that most foil faced systems act as a vapor retarder)	Easy installation: All suitable for framing at standard spacing Bubble-form suitable if framing is irregular or if obstructions are present

Insulation

Ensure that insulation is installed properly. This is important to the overall energy performance of the building and can also affect the durability of the wall structure. Plans and drawings should specify that insulation not be compressed behind wiring or plumbing. Compressed insulation will have a reduced *R*-value, lowering the efficiency of the insulation.

Specify that insulation fills the entire cavity. Batts that are cut too short will leave voids in the wall reducing effectiveness of the insulation. For continuous insulation, make sure there are no voids and that the insulation is well bonded to the outside of the framing. It is important to install insulation in exterior corners and on or in headers over doors and windows. This can eliminate excess heat transfer through the surfaces. Concrete masonry unit walls may be insulated by filling the empty core with perlite, vermiculite, or some other insulating material.

In some cases, even with filled cores, these wall types require additional insulation. The insulation will either be installed between framing members, typically on the inside of the wall, or as continuous rigid board insulation on the inside or outside of the wall. In either case, make sure that the insulation is installed properly and that the insulation *R*-value matches the plans or documentation.

Thermal Values of Common Construction Materials[6]

Brick, concrete, stone and plastering material are all common materials in India used for opaque wall construction. Summary of each material along with tables describing basic thermal properties is given below:

Bricks: These are locally produced and vary in the quality of the raw material, manufacture process, and finished product. Standard burnt clay bricks follow Indian Standard IS: 1077: 1992, which specifies a compressive strength of less than 40 N/mm^2.

Also commonly used are *Burnt Clay Fly Ash Bricks*, which have higher compressive strength than the standard bricks. *Burnt Clay Hollow Bricks* are a third type of brick available; these have excellent strength and durability qualities.

Stone: Although the density of stone is very high, sandstone has a low R-value due to its high conductivity. This can be improved by increasing the thickness of material in the walls.

Concrete: Made from cement and additional materials, such as fly ash, slag cement, aggregate, and chemical admixtures, concrete is poured or used in blocks.

Plastering Material: Additional thermal value is added to the wall through plastering materials used to provide a smooth interior surface.

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[6] Source: Dr. -Ing Jyotirmay Mathur, Malaviya National Institute of Technology

Table 7: Thermal Properties of Commonly Used Construction Materials in India

		Thermal Properties			
Basic Material	Type	Density (ρ) (kg/m^3)	Conductivity (k) (W/m·K)	Resistance (R) Per inch thickness (1/k) (m·K/W)	Specific Heat (C_P) (KJ/kg·K)
Brick	**Burnt Clay**	2400	1.21-1.47	0.83-0.68	-
		2240	1.07-1.30	0.94-0.77	-
		1920	0.81-0.98	1.24-1.02	0.79
		1600	0.61-0.74	1.65-1.36	-
Stone	**Sand Stone**	**2880**	**10.4**	**0.10**	**0.73**
		2240	3.5	0.29	
		1920	1.9	0.53	
Concrete Blocks	**Solid Blocks**[a]	2000	1.3	0.769	-
		1400	0.56	1.785	-
		800	0.26	3.84	-
	Hollow Blocks[b]	1360	0.9616	1.039	-
		1040	0.618	1.61	0.837
		880	0.480	2.08	0.837
Concrete	**Lime Stone Concrete**	2240	1.6	0.62	-
		1920	1.14	0.88	
		1600	0.79	1.26	
	Gypsum Fiber Concrete	816	0.24	4.18	0.88
	Cement / Lime and Mortar	1920	1.4	0.7	-
		1600	0.97	1.04	
		1280	0.65	1.54	
	Foam Concrete	1920	0.7	1.32	-
		1600	0.6	1.66	
		1280	0.44	2.29	
Cement Plaster	**Sand Aggregate (10 mm)**	1860	75.5	0.013	0.84
	Sand Aggregate (20 mm)	1860	37.8	0.026	
Gypsum Plaster	**Light weight (13mm)**	720	17.7	0.056	-
Perlite	**Sand Aggregate (13 mm)**	1680	63	0.016	-

Source: ASHRAE Hand Book (1997), Chapter 24

Source: [a]5250 UK, [b]Hollow DOE-2 PROGRAM, USA

The thermal properties of commonly used insulating materials are shown below in **Error! Not a valid bookmark self-reference.**

Table 8: Thermo Physical Properties of Various Thermal Insulating Materials

S. No	Type	Insulating Materials	Thickness (mm)	Thermal Resistance (R)		Specific heat (C_P) (KJ/kg·K)
				For the Given Thickness (1/C) (m^2·K/W)	Per inch thickness (1/*k*) (m·K/W)	
1	Flexible	Mineral Fiber (rock, slag or glass)	90	2.63	-	-
			140	3.67	-	-
		Glass Fiber, organic bonded	-	-	27.7	0.96
		Expanded Polystyrene (Extruded)	-	-	34.7	1.21
		Cellular glass	-	-	19.8	0.75
2	Loose Fill	Wood Pulp	-	-	25.6-21.7	1.38
		Perlite	-	-	25.6-22.9	1.09
		Vermiculite	-	-	14.8	1.34
3	Spray	Glass Fiber	-	-	26.7-25.6	-
		Cellulosic fiber	-	-	23.9-20.4	-
		Polyurethane foam	-	-	43.3-38.5	-
4	Air Cavity		1.76	0.57	-	-

Source: ASHRAE Handbook (1997), Chapter 24

4.3.3 Vertical Fenestration

The ECBC addresses energy losses through fenestration by specifying the following fenestration requirements: minimum U-Factor or Thermal Transmittance, maximum Solar Heat Gain Coefficient (SHGC), and maximum window to wall ratio (WWR) of 60% for the Prescriptive Compliance Approach.

Vertical fenestration should meet the requirements for maximum area weighted U-factor and maximum area weighted SHGC. The ECBC limits the area of vertical fenestration, under the prescriptive approach, to a maximum of 60% of the gross wall area.

The U-factor and SHGC requirements of the rated (labeled) fenestration for two WWR ranges for Code compliance are given in Table 4.3 of ECBC (reproduced in Table 9).

Table 9: Vertical Fenestration U-Factor and SHGC Requirements

		WWR≤40%	40% <WWR≤60%
Climate	Maximum U-factor	Maximum SHGC	Maximum SHGC
Composite	3.30	0.25	0.20
Hot and Dry	3.30	0.25	0.20
Warm and Humid	3.30	0.25	0.20
Moderate	6.90	0.40	0.30

Cold	3.30	0.51	0.51

See Appendix C of ECBC for Defaults values of Unrated Fenestration Values for unrated windows must follow the values given in Table 11.1 of Appendix C of ECBC (reproduced in Table 10).

Table 10: Defaults for Unrated Vertical Fenestration (Overall Assembly including Sash and Frame)

		Clear Glass			Tinted Glass		
Frame Type	Glazing Type	U-Factor (W/m^2-^oC)	SHGC	VLT	U-Factor (W/m^2-^oC)	SHGC	VLT
All frame types	Single Glazing	7.1	0.82	0.76	7.1	0.70	0.58
Wood, vinyl, or fiberglass frame	Double Glazing	3.3	0.59	0.64	3.4	0.42	0.39
Metal and other frame type	Double Glazing	5.1	0.68	0.66	5.1	0.50	0.40

Energy Efficient Fenestration Products/Assemblies.

Windows are affected by many factors, which in turn affect the comfort and energy performance of buildings. Understanding these factors is critical in designing buildings that meet the needs of building owners and users. Once these factors are identified, a designer can then apply the appropriate technology to address them.

A fenestration product is comprised of three areas, the vision area, the glazing, and the opaque area or the frame. In a window, glazing is generally 90-95% of the total area and therefore the most important part to address for achieving energy efficiency. However, the frame becomes important to optimize the overall energy efficiency of the window.

The energy efficiency of a fenestration product is effected by:

Films which are applied to improve energy efficiency
Low emissivity (Low-E) coatings for energy-efficient windows
Gas fill used in insulating glass units for energy-efficient windows
Warm edge insulating glass units for energy-efficient windows
Frame designs for energy-efficient windows
Reducing the air leakage of windows to improve energy efficiency
Number of layers of glass in the fenestration product.

The technology for producing energy-efficient windows relies heavily on the development of low-e coatings for glass. These can also be regarded as 'spectrally selective' coatings because their properties vary depending on the wavelength of the incident radiation. A low-e coating allows the visible light to pass through relatively unaffected whole rejecting invisible infrared heat. For example, an emissivity of 0.10 means that 90% of the long heat radiation is reflected back.

The thermal properties of sample glazing products are shown in Table 11 and Table 12.

Colour Shade	Brand	Code	Solar Heat Gain Coefficient	U value	Relative Heat Gain
			SHGC	W/ sqM K	W/ Sqm

Single Glazed Unit (6mm thick, coating face 2)					
Light Gold	Reflectasol		0.52	5.7	410
Dew Drop	Antelio Plus	ST 150	0.56	5.7	454
Sparkling Ice	Antelio Plus	ST 167	0.67	5.6	536
Graphite	Cool-lite	ST 136	0.44	5.5	373
Double Glazed Unit (outer: 6mm with coating Face 2 - 12mm Air Gap - inner 6mm Clear)					
Light Gold	Reflectasol		0.44	2.8	331
Dew Drop	Antelio Plus	ST 150	0.45	2.8	359
Sparkling Ice	Antelio Plus	ST 167	0.58	2.8	445
Graphite	Cool-lite	ST 136	0.34	2.76	281
Pristine White	Planitherm	PLT T	0.54	1.77	427
Moonshine	Nano	KT 155	0.36	1.86	290
	Nano	kt 140	0.29	1.8	172
Double Glazed Unit (outer: 6mm with coating Face 2 - 12mm Air Gap - inner 6mm Planitherm Total (Low E coating Face 3))					
Light Gold	Reflectasol		0.33	1.77	256
Dew Drop	Antelio Plus	ST 150	0.38	1.77	300
Sparkling Ice	Antelio Plus	ST 167	0.48	1.77	376
Graphite	Cool-lite	ST 136	0.28	1.77	232
Pristine White	Planitherm	PLT T	0.51	1.7	408
Moonshine	Nano	KT 155	0.34	1.7	273

Table 12

Table 11 Sample Glazing Products and Thermal Qualities

Colour Shade	Brand	Code	Solar Heat Gain Coefficient	U value	Relative Heat Gain

			SHGC	W/ sqM K	W/ Sqm
Single Glazed Unit (6mm thick, coating face 2)					
Light Gold	Reflectasol		0.52	5.7	410
Dew Drop	Antelio Plus	ST 150	0.56	5.7	454
Sparkling Ice	Antelio Plus	ST 167	0.67	5.6	536
Graphite	Cool-lite	ST 136	0.44	5.5	373
Double Glazed Unit (outer: 6mm with coating Face 2 - 12mm Air Gap - inner 6mm Clear)					
Light Gold	Reflectasol		0.44	2.8	331
Dew Drop	Antelio Plus	ST 150	0.45	2.8	359
Sparkling Ice	Antelio Plus	ST 167	0.58	2.8	445
Graphite	Cool-lite	ST 136	0.34	2.76	281
Pristine White	Planitherm	PLT T	0.54	1.77	427
Moonshine	Nano	KT 155	0.36	1.86	290
	Nano	kt 140	0.29	1.8	172
Double Glazed Unit (outer: 6mm with coating Face 2 - 12mm Air Gap - inner 6mm Planitherm Total (Low E coating Face 3))					
Light Gold	Reflectasol		0.33	1.77	256
Dew Drop	Antelio Plus	ST 150	0.38	1.77	300
Sparkling Ice	Antelio Plus	ST 167	0.48	1.77	376
Graphite	Cool-lite	ST 136	0.28	1.77	232
Pristine White	Planitherm	PLT T	0.51	1.7	408
Moonshine	Nano	KT 155	0.34	1.7	273

Table 12: Performance and Cost Estimates for Glazing Products

Inner Glass	Color Shade	Brand	Code	Light Transmission %	SHGC	U Value $W/m^2.K$
None	Green	Reflectasol	Reflectasol Green	26	0.37	5.73
6mm Clear Glass Tempered	Green	Reflectasol	Reflectasol Green	24	0.26	2.83
6mm Clear Glass Tempered	Titanium Blue	Cool-lite	STB 120	20	0.24	2.7
6mm Clear Glass Tempered	Tranquil Blue	Cool-lite	ST 720	12	0.18	2.64
6mm Clear Glass Tempered	Blue Breeze	Cool-lite	ST 736	22	0.25	2.76
6mm Clear Glass Tempered	Misty Blue	Nano	KT 755	33	0.25	1.8
6mm Clear Glass Tempered	Twilight Blue	Nano	KT 740	24	0.2	1.8

6mm Low E Glass Tempered	Sapphire Blue	Reflectasol	Reflectasol Sapphire Blue	17	0.21	1.8
6mm Low E Glass Tempered	Royale Blue	Antelio Plus	ST 750	28	0.25	1.77
6mm Clear Glass Tempered	Sterling Silver	Cool-lite	ST 120	18	0.22	2.6
6mm Low E Glass Tempered	Bronze	Reflectasol	Reflectasol Bronze	15	0.24	1.77
6mm Low E Glass Tempered	Sterling Silver	Cool-lite	ST 120	17	0.18	1.76
6mm Clear Glass Tempered	Turquoise	Cool-lite	ST 436	27	0.25	2.76
6mm Low E Glass Tempered	Blue Green	Antelio Plus	ST 450	35	0.25	1.77
6mm Clear Glass Tempered	Aquamarine	Cool-lite	ST 420	15	0.18	2.64
6mm Clear Glass Tempered	Olive	Nano	KT 455	39	0.25	1.86
6mm Clear Glass Tempered	Tropica Green	Nano	KT 440	30	0.22	1.79
6mm Low E Glass Tempered	Green	Reflectasol	Reflectasol Green	22	0.19	1.77

Source: St. Gobain

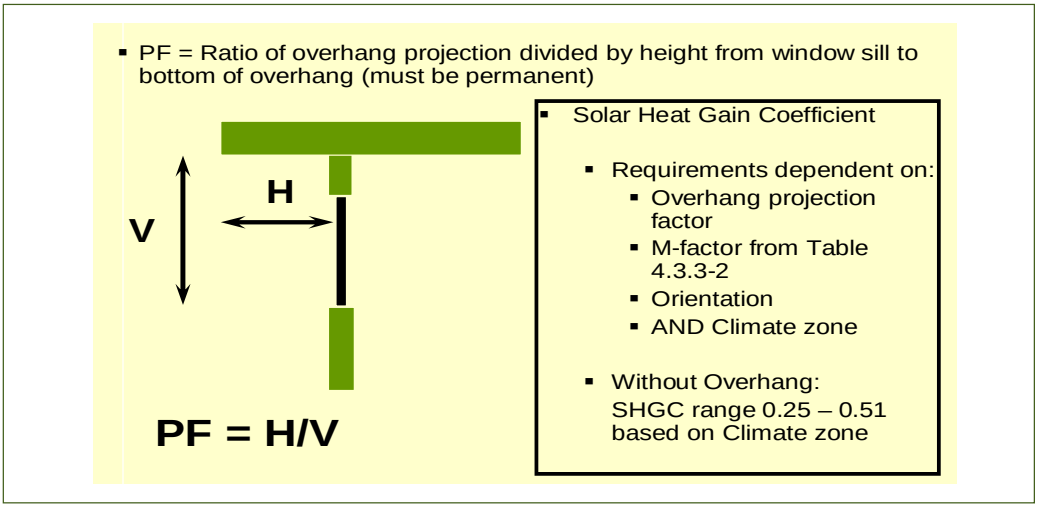
Note: Price is assumed without any geometric wastage even though there could be wastage depending on the panel sizes used in the building. Geometric wastage in India is assumed to be in the range of 5-15%. Outer glass is assumed Heat Strengthened to avoid thermal breakage (common practice in India); inner glass is assumed to be tempered for safety (not standard in India). Price is based on what the manufacturer would invoice to the glass installer (fabrication company), which gets an additional margin of 5-10% from the developer (builder) for handling, storage, etc.

Overhangs (Exception to ECBC Section 4.3.3): The SHGC requirement of a window can be affected by overhangs on a building, which reduce solar gains. The ECBC uses a term called a projection factor to determine how well an overhang shades the building's glazing. The projection factor is calculated by measuring the distance from the window to the farthest-most edge of the overhang and dividing that by the distance from the bottom of the window to the lowest point of the overhang. **Error! Reference source not found.** demonstrates how to calculate a projection factor.

Projection Factor = H (horizontal) / V (vertical)

The ECBC provides a modified SHGC requirement where there are overhangs and/or side fins, which are a permanent part of the building. This may be applied in determining the SHGC for the proposed design. An adjusted SHGC, accounting for overhangs and/or sidefins, is calculated by multiplying the SHGC of the unshaded fenestration product by a multiplication (M) factor. If this exception is applied, a separate M Factor shall be determined for each orientation and unique shading condition.

Figure 11: Projection Calculation


PF = Ratio of overhang projection divided by height from window sill to bottom of overhang (must be permanent)
V
H
PF = H/V
Solar Heat Gain Coefficient
Requirements dependent on:
Overhang projection factor
M-factor from Table 4.3.3-2
Orientation
AND Climate zone
Without Overhang:
SHGC range 0.25 – 0.51 based on Climate zone

ECBC Table 4.4 (reproduced in Table 13) provides the values of M-factor for various projection factors.

Table 13: SHGC "M" Factor Adjustments for Overhangs and Fins

		Overhang "M" Factors for 4 Projection Factors				Vertical Fin "M" Factors for 4 Projection Factors				Overhang +Fin "M" Factors for 4 Projection Factors			
Project Location	Orientation	0.25 - 0.49	0.50 - 0.74	0.75 - 0.99	1.00 +	0.25 - 0.49	0.50 - 0.74	0.75-0.99	1.00 +	0.25 - 0.49	0.50 - 0.74	0.75 - 0.99	1.00 +
North latitude 15° or greater	N	.88	.80	.76	.73	.74	.67	.58	.52	.64	.51	.39	.31
	E/W	.79	.65	.56	.50	.80	.72	.65	.60	.60	.39	.24	.16
	S	.79	.64	.52	.43	.79	.69	.60	.56	.60	.33	.10	.02
Less than 15° North latitude	N	.83	.74	.69	.66	.73	.65	.57	.50	.59	.44	.32	.23
	E/W	.80	.67	.59	.53	.80	.72	.63	.58	.61	.41	.26	.16
	S	.78	.62	.55	.50	.74	.65	.57	.50	.53	.30	.12	.04

Example 4 : Prescriptive Requirements for Fenestration

Location: Chandigarh

Climate Zone – Composite (Lat: : 30° 42' N; Long : 76° 54' E)

Building Type: Daytime Use Building

Roof Area: 568 m^2

Roof Insulation: Rigid Board 1 inch R = 2.1 m^2-°C/W

Wall Area: 1130 m^2

Wall Insulation: Rigid Board 1 inch R = 1.41 m^2-°C/W

Total Fenestration Area: 508 m^2

Window to Wall ratio: 508/1130 = 45%

East/West and South facing windows are all 1.82880 m x 0.91440 m wide with a 0.45720 m overhang and represent 75 % of the glazing on the building.

Projection Factor: H/V = 0.45720/1.82880 = 0.25

"M" factor: 0.79 (From ECBC Table 4.4, Projection Factor=0.25, E/W and S orientation for north latitude 15 Deg. Or greater)

East/West and South facing glazing: 508 x 0.75 = 381 m^2

North Facing Fenestration: SHGC 0.20; U – factor 3.30

East/West and South Facing Fenestration: Skylight Area 10.8 m^2

Skylight to Roof Area 10.8/568 = 1.9%

Does my building envelope comply Prescriptively with the ECBC?

A: To utilize the prescriptive requirements of ECBC, vertical fenestration is limited to 60% of the gross wall area, so this building is allowed under this method.

ECBC Table 4.3 limits the SHGC value to a maximum of 0.20 for composite climate zone, however an exception exists by use of an overhang. ECBC Section 4.3.3 allows for an "M" Factor, or multiplier. In this case the M is 0.79.

Multiplying "M" times the SHGC [0.7900* 0.25=0.1975] and thus complies with ECBC Table 4.3.

SHGC Requirements (Exception to ECBC Section 4.3.3): In addition to the SHGC exception above for overhangs and/or side fins, the ECBC encourages the use of daylighting by allowing for SHGC exceptions for vertical fenestration located more than 2.2 m (7 ft) above the level of the floor provided the following conditions are complied with:

The Total Effective Aperture for the elevation is less than 0.25, including all fenestration areas greater than 1.0 m (3ft.) about the floor level, and

An interior light shelf is provided at the bottom (2.2 m or higher) of this fenestration area, with an interior projection factor (PF) not less than:

- for E-W, SE, SW, NE, and NW orientations
- 0.5 for S orientations, and
- 0.35 for N orientation when latitude is < 23 degrees

Daylighting Strategies

Effective daylighting strategies should include some combination of the following:

- Exterior shading – Overhangs and vertical fins block direct sun and can bounce reflected light into interior spaces.
- Interior light distribution – Light shelves, diffusers, or reflective surfaces move the light further back into the space.
- Daylighting controls – Automatic or manual controls dim or turn-off electric lighting when there is sufficient daylight present.*

**Refer to Section 7.2.1.3 (Control in Daylighted Areas) for control device requirements.*

EXTERIOR SHADING DEVICES DESIGN TIPS

Design the building to shade it. Use the building form itself to provide exterior shading, by recessing the window back in a deeper wall section or extending elements of the skin to visually blend with envelope structural features.

Use a horizontal form for south windows. For example, awnings, overhangs, recessed windows. Also somewhat useful on the east and west. Serves no function on the north.

Use a vertical form on east and west windows.

For example, vertical fins or recessed windows. Also useful on north to block early morning and late afternoon low sun.

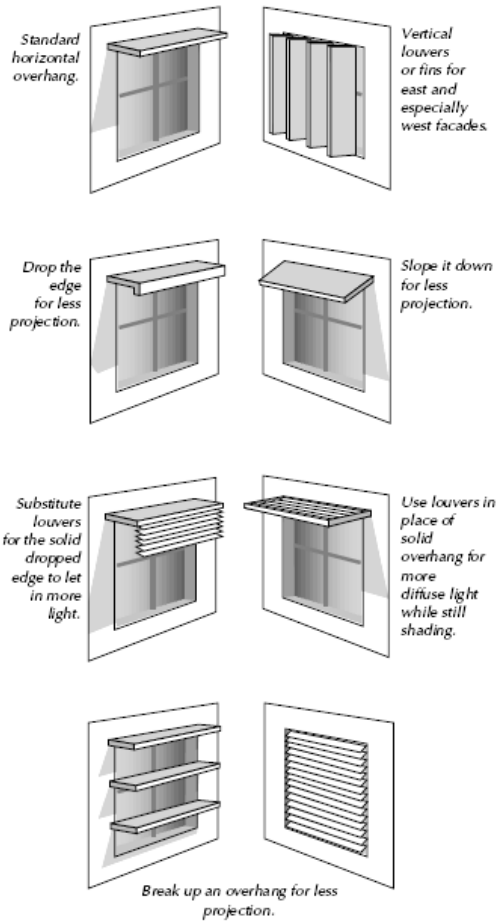
Give west and south windows shading priority. Morning sun is usually not a serious heat gain problem. If your budget is tight, invest in west and south shading only.

Design shading for glare relief as well. Use exterior shading to reduce glare by partially blocking occupants' view of the too-bright sky. Exterior surfaces also help smooth out interior daylight distribution.

The shade's color modifies light and heat. Exterior shading systems should be light colored if diffuse daylight transmittance is desired and dark colored if maximum reduction in light and heat gain is desired.

Fixed versus movable shading. Use fixed devices if your budget is tight. Use movable devices for more efficient use of daylight and to allow occupant adjustment; first cost and maintenance costs are higher than with fixed devices. Use movable devices that are automatically controlled via a sun sensor for the best energy savings.

Source: Lawrence Berkeley National Laboratory (1997). Tips for Daylighting with Windows. Available from http://windows.lbl.gov/daylighting/designguide/dlg.pdf

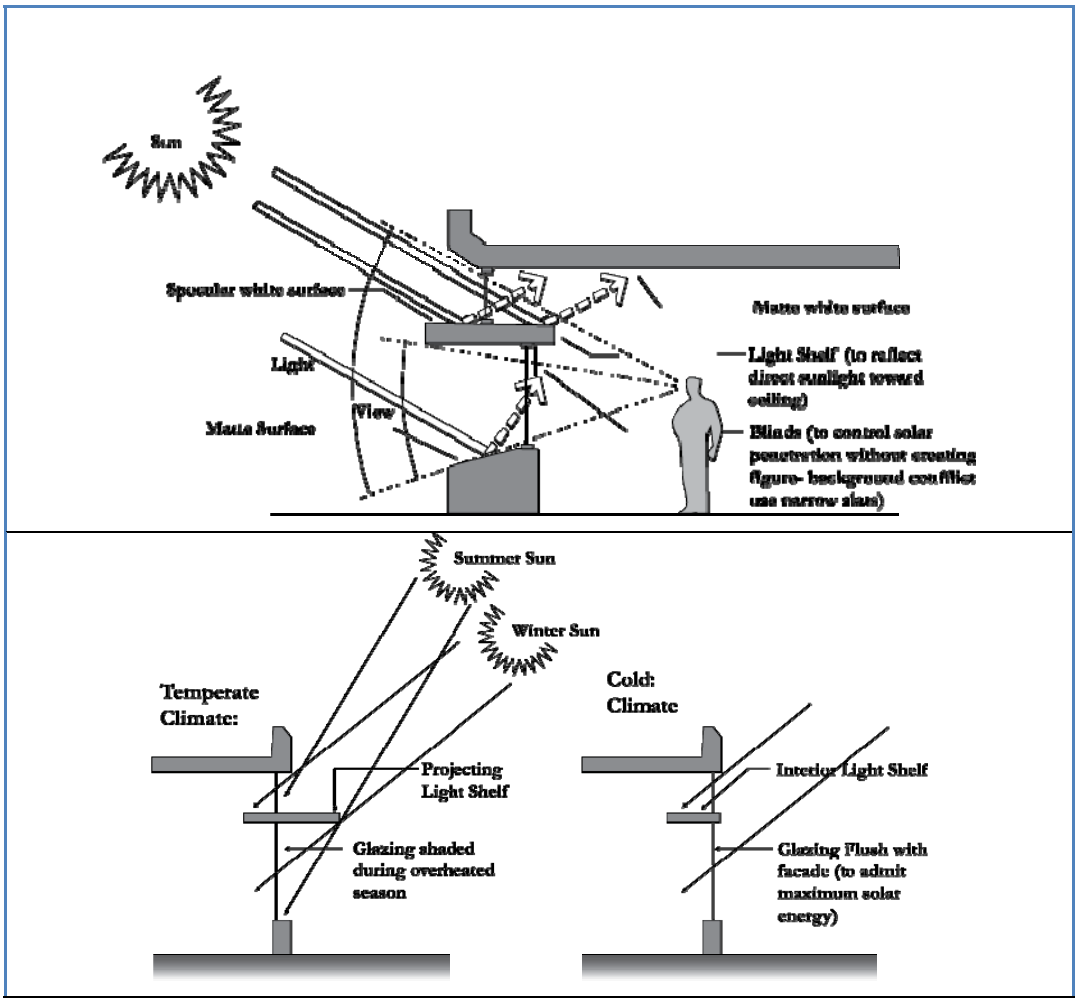

Standard horizontal overhang.
Vertical louvers or fins for east and especially west facades.
Drop the edge for less projection.
Slope it down for less projection.
Substitute louvers for the solid dropped edge to let in more light.
Use louvers in place of solid overhang for more diffuse light while still shading.
Break up an overhang for less projection.

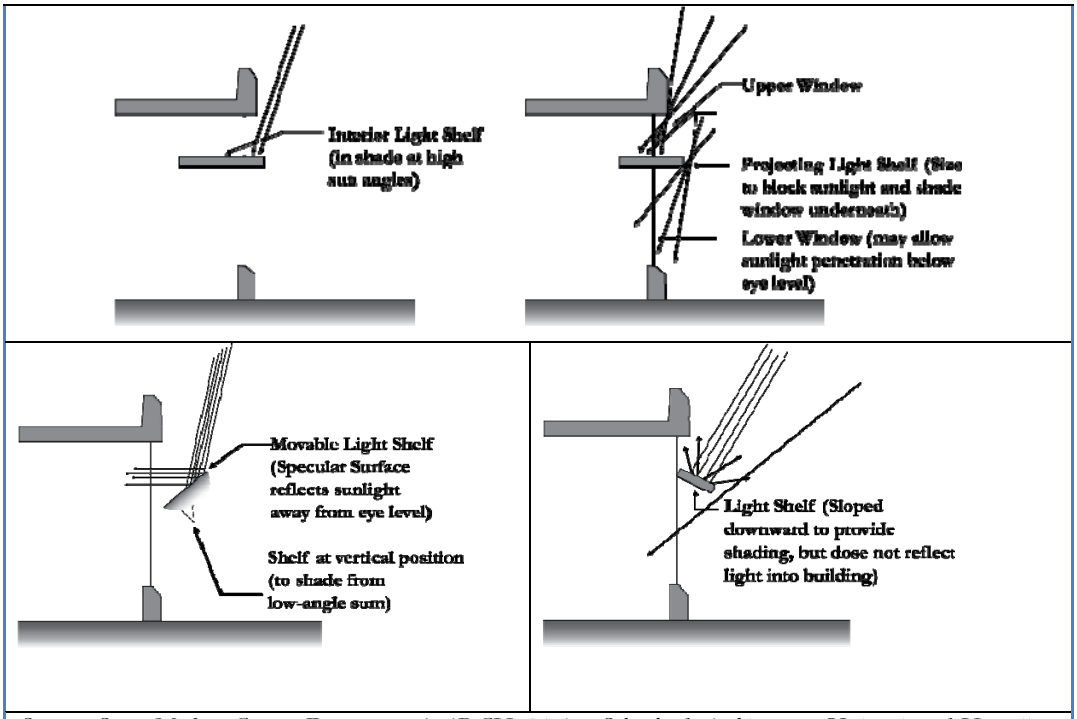
FAQ 4: What is a Light Shelf?

A light shelf is a horizontal light-reflecting overhang placed above eye-level with a transom window placed above it. This design, which is most effective on southern orientations, improves daylight penetration, creates shading near the window, and helps reduce window glare. Exterior shelves are more effective shading devices than interior shelves. A combination of exterior and interior will work best in providing an even illumination gradient.

Since luminance ratio (brightness) is a major consideration in view windows, it is often wise to separate the view aperture from the daylight aperture. This allows a higher visible transmittance glazing in the daylight aperture if it is out of normal sight lines. Since the ceiling is the most important light-reflecting surface, using this surface to bounce daylight deep into the room can be highly effective. Both of these strategies are utilized in light shelf designs.

Figure 12: Light Shelf Examples and Design Tips





Source: Steve Meder, Course Documents (ARCH 316), School of Architecture, University of Hawaii at Manoa

4.3.3.1 (Minimum) Visible Transmission of Glazing for Vertical Fenestration.

The ECBC encourages the use of daylighting features in buildings by defining the minimum Visual Light Transmittance (VLT) levels for vertical fenestration. The prescriptive requirements place minimum limits on VLT, with respect to variation in WWR. Determine the window-to-wall ratio and meet the corresponding VLT minimum in ECBC Table 4.5 to implement allowable daylighting strategies.

Vertical fenestration products must meet the minimum VLT, defined as a function of Window Wall Ratio (WWR), where Effective Aperture > 0.1, equal to or greater than the Minimum VLT requirements of ECBC Table 4.5 (reproduced below in **Error! Reference source not found.**):

Table 14: Minimum VLT Requirements

Window Wall Ratio	Minimum VLT
0 - 0.3	0.27
0.31-0.4	0.20
0.41-0.5	0.16
0.51-0.6	0.13

Effective Aperture

Effective Aperture: One method of assessing the relationship between visible light and the size of the window is the effective aperture method. The effective aperture (EA) is defined as the product of the *visual light transmittance* and the window-to-wall ratio. The *window-to-wall ratio* (WWR) in this case, is the proportion of window area compared to the total wall area where the window is located, i.e., that particular elevation. For example, if a window covers 25 square feet in a 100 square-foot wall then the WWR is 25/100 or 0.25. For a given EA number, a higher WWR (larger window) results in a lower visible transmittance.

Example: WWR = 0.5 (half the wall in glazing)
VLT = 0.16, EA = 0.08

Or WWR = 0.70, VLT = 0.11 for same EA of 0.077

(Typically lowering the visible light transmittance will also lower the shading coefficient but you must verify this with glazing manufacturer data since this is not always the case.)

4.3.4 Skylights

A skylight is a fenestration surface having a slope of less than 60 degrees from the horizontal plane. Other fenestration, even if mounted on the roof of a building, is considered vertical fenestration.

Skylights can be installed into a roof system either flush-mounted or curb-mounted (including site built). In order to create a positive water flow around them, skylights are often mounted on "curbs" set above the roof plane. However, these curbs, rising 6 to 12 inches (15 to 30 centimeters) above the roof, create additional heat loss surfaces right where the warmest air of the building tends to collect. Portions of roof that serve as curbs that mount the skylight above the level of the roof (See **Error! Reference source not found.**4 below) are part of the opaque building envelope.

The SHGC criteria for skylights depends on the percentage of skylight glazing, and the U-factor criteria depends on whether or not the skylight is intended to be mounted on a curb. Skylights need to comply with the maximum U-factor and maximum SHGC requirements of ECBC Table 4.6 (reproduced below in Table 15). Also, skylight area is limited to a maximum of 5% of the gross roof area under the prescriptive approach requirements. Buildings that have a skylight-roof ratio greater than 5% must use the Building Envelope Trade- off Option or the Whole Building Performance Method.

Figure 13: Skylight Installations

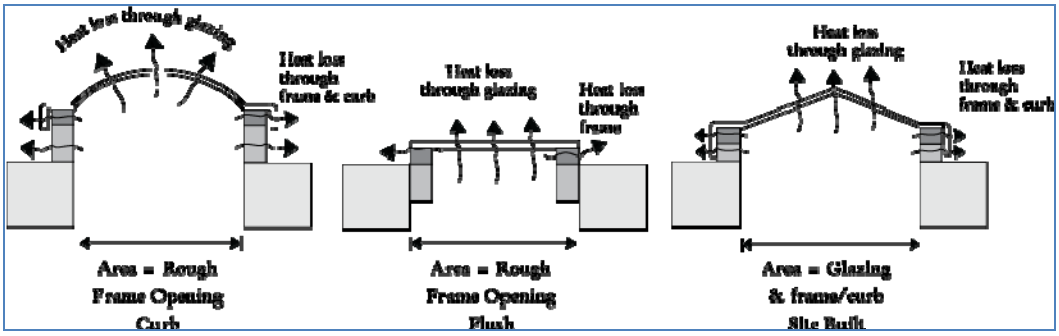


Table 15: Skylight U-Factor and SHGC Requirements

	Maximum U-factor		Maximum SHGC	
Climate	With Curb	w/o Curb	0-2% SRR	2.1-5% SRR
Composite	11.24	7.71	0.40	0.25
Hot and Dry	11.24	7.71	0.40	0.25
Warm and Humid	11.24	7.71	0.40	0.25
Moderate	11.24	7.71	0.61	0.4
Cold	11.24	7.71	0.61	0.4

SRR = *Skylight roof ratio which is the ratio of the total skylight area of the roof, measured to the outside of the frame, to the gross exterior roof. See Section 11.2.2 for typical complying skylight constructions.*

Example 5 : Prescriptive Requirements for Skylights

Location: Chennai **Climate Zone** - Warm-Humid

Building Type: Daytime Use Building

Roof Area: 1,863 sq m **Roof Insulation:** Rigid Board 1 inch R= 2.1 m^2-°C/W

Wall Area: 3,706 sq m **Wall Insulation:** Rigid Board 1 inch R= 1.41 m^2-°C/W

Fenestration Area: 487 sq m

Window to Wall ratio: 487/3706 = 13%

Fenestration: SHCG 0.20 U – factor 3.30

Skylight Area:112 sq m

Skylight to Roof Area:112/1863= 6%

Does my building envelope comply *Prescriptively* with the ECBC?

No, this building does not comply because the prescriptive approach limits skylights area to a maximum of 5% of the roof area. This building would need to comply under the envelope trade off option of the Whole Building Approach.

As with windows, the skylight-roof ratio must be calculated separately for each space category. The criteria for each space category are determined from its own skylight-roof ratio, not the skylight-roof ratio for the whole building.

FAQs 5: Glazing

What is the most important feature that a building professional should look for regarding windows, doors, and skylights?

The SHGC and U-factor ratings are the most important items to verify during inspections. Building professionals should verify that the ratings of the installed windows, doors, and skylights meet or exceed the ratings specified on the plans. It is also important to verify that the same window area has been installed as the area shown on the plans and that the glass orientation on the plans and building are consistent.

What is the Solar Heat Gain Coefficient?

The Solar Heat Gain Coefficient (SHGC) is a measure of the percentage of heat from the sun

that gets through a window or other fenestration product. The SHGC is expressed as a number between 0 and 1. The lower a window's SHGC, the less solar heat it transmits to the interior of the building. SHGC can also refer to shading so the lower the SHGC the more effective the product is at shading the heat gain from entering the interior.

What is low-e glass?

Low-e stands for low-emissivity and refers to a special coating that reduces the heat transfer of a window assembly. Low-e coated products that reduce solar heat gain can be produced by adding a metallic coating either while the glass is in a molten state or by applying to the glass after it has cooled to a solid state. Low-e glass is readily available from all the glass and window manufacturers. The coatings typically add about 10% to the cost of a window but costs vary by product type, by manufacturer, by retailer and by location.

What is spectrally selective glass?

The sun emits visible solar radiation in the form of light and infra-red radiation that cannot be seen, but causes heat. Spectrally selective glass transmits a high proportion of the visible solar radiation, but screens out radiant heat from the sun – significantly reducing the need to cool a building's interior. Spectrally selective glass is used to describe low-e coated glass that lowers the SHGC.

How can I be sure I have spectrally selective glass?

The SHGC rating for the product is the key to determining whether you have glass with a spectrally selective coating. In general, windows with a spectrally selective low-e coating will have SHGC ratings of 0.40 or lower.

4.4 BUILDING ENVELOPE TRADE-OFF OPTION

Formulas in Appendix D guide calculation of the envelope performance factor. This is calculated for a subject building AND for a standard design (standard design refers to a building envelope exactly meeting prescriptive requirements). For compliance, the subject building's performance factor must be less than that of the standard design.

5 HEATING, VENTILATION AND AIR CONDITIONING

5.1 GENERAL

Overview

Heating, Ventilation and Air Conditioning (HVAC) refers to the equipment, distribution network, and terminals that provide, either collectively or individually, the heating, ventilating, or air-conditioning processes to a building. The HVAC system accounts for significant portion of a commercial building's energy use – approximately 40 percent. However, proven technologies and design concepts can be used to build energy efficiencies in the system and generate significant energy and cost savings.

HVAC systems are also critical for their effect on the health, comfort, and productivity of occupants. Issues like user discomfort, improper ventilation, and poor indoor air quality are linked to HVAC system design and operation and can be improved by better mechanical and ventilation systems. In many existing buildings, envelope upgrades are often necessary to improve comfort and energy efficiency, through improvements such as reducing envelope leakage.

The best HVAC design considers all the interrelated building systems while addressing indoor air quality, thermal comfort, energy consumption, and environmental benefit. Optimizing both the design and the benefits requires that the architect and mechanical system designer address these issues early in the schematic design phase and continually revise subsequent decisions throughout the remaining design process. It is also essential that a process is implemented to monitor proper installation and operations of the HVAC system throughout construction. An effective routine preventative maintenance program should also be delivered to the owner at the building's completion to ensure that the building operator maintains temperature settings and schedules that deliver energy savings and comfort. The tip box below presents six key steps for the design of a high performance and energy efficient HVAC system.

SEQUENTIAL PROCESS FOR ENERGY EFFICIENT HVAC SYSTEM DESIGN		
1	ADOPT AN INTEGRATED BUILDING DESIGN SOLUTION	Integrate the architectural and engineering concerns early on in the design process
2	ESTABLISH DESIGN CONDITIONS	Optimize system design based on differences in the activity levels, ventilation & thermal comfort requirements, internal loads and energy performance criteria.
3	"RIGHT SIZE" SYSTEM & IT'S COMPONENTS	Use accurate heating & cooling load calculations to avoid over-sizing or under-sizing system. Plan & make provisions for future building expansions
4	CONSIDER PART LOAD PERFORMANCE SELECTION CRITERIA	Peak load conditions historically occur only 1-2.5% of the time. Select systems that can operate efficiently at part-load:- Eg. Variable capacity boilers, chillers, compressor equipment, pumps, motors and use temperature reset controls for hot water, chilled water, and supply air.
5	PERFORM SYSTEM COMMISSIONING	Test the HVAC systems under all aspects of operation, to reveal and rectify problems, thereby ensuring that the system performs as intended.
6	ESTABLISH AN OPERATIONS & MAINTENANCE (O&M) PROGRAM	Make systems control, operations, & maintenance training a part of the construction contract. Establish a written, comprehensive O&M program for all equipment and system controls, based on the requirements of the facility, equipment, and systems installed.

HVAC Basics

Heating Ventilation and Air Conditioning (HVAC) systems employ the same operating principles and basic components as a refrigerator. An air-conditioner cools with a cold indoor coil called the evaporator. The condenser, a hot outdoor coil, releases the collected heat outside. The evaporator and condenser coils are serpentine tubing surrounded by aluminum fins. This tubing is usually made of copper. A pump, called the compressor, moves a heat transfer fluid (or refrigerant such as ammonia and fluorinated hydrocarbons) between the evaporator and the condenser. The pump forces the refrigerant through the circuit of tubing and fins in the coils. The liquid refrigerant evaporates in the evaporator coil, pulling heat out of indoor air and thereby cooling the space. The hot refrigerant gas is pumped into the condenser where it reverts back to a liquid giving up its heat to the air flowing over the condenser's metal tubing and fins. Because the condenser is the heat rejection unit so it should be located in such a manner that the heat sink is free of interference from heat discharge of other equipment for optimum performance.

Type of Air-Conditioners

The most common types of air-conditioners are room (unitary) air-conditioners, split-system central air-conditioners, packaged air-conditioners, and central air-conditioners. The unitary and packaged systems offer localized solutions for a building's heating and cooling needs. These systems are typically appropriate for smaller (single-zone) buildings. Compared to local HVAC systems, in most conventional commercial buildings, a central HVAC will be able to provide better thermal comfort and meet energy efficiency parameters.

Local HVAC Systems

Room (Unitary) and split air-conditioners: Room air-conditioners cool rooms rather than the building, and provide cooling only when needed. Room air-conditioners are less expensive to operate than central units, even though their efficiency is generally lower than that of central air-conditioners. In a split-system central air-conditioner, an outdoor metal cabinet contains the condenser and compressor, and an indoor cabinet contains the evaporator. In many split-system air-conditioners, this indoor cabinet also contains a furnace or the indoor part of a heat pump.

Packaged air-conditioners: In a packaged air-conditioner, the evaporator, condenser, and compressor are all located in one cabinet, which usually is placed on a roof or on a concrete slab adjacent to the building. This type of air-conditioner is typical in small commercial buildings and also in residential buildings. Air supply and return ducts come from indoors through the building's exterior wall or roof to connect with the packaged air-conditioner, which is usually located outdoors. Packaged air-conditioners often include electric heating coils or a natural gas furnace. This combination of air-conditioner and central heater eliminatesthe need for a separate furnace indoors.

Central HVAC Systems

Central air-conditioners: In central air-conditioning systems, cooling is generated in a chiller and distributed to air-handling units or fan-coil units with a chilled water system. This category includes systems with air-cooled chillers as well as systems with cooling towers for heat rejection.

Table 16 is a comprehensive overview of the differences between local and central HVAC systems. These differences can provide as guidelines for choosing the appropriate system type for the building.

Table 16: Overview of local and central HVAC systems

	CENTRAL SYSTEMS	LOCAL SYSTEMS
Building Space Requirements	Will require separate building space to house the chillers, boilers, pumps, AHU's, distribution networks and control panels. In addition, space is required outdoors for condensing unit for air-cooled machines and cooling tower for water-cooled machines. The building structure should be designed to take the weight of equipment. Suitable vibration control must be considered and adequate load bearing beams and columns must be available for lifting and shifting of such equipment.	No separate plant room space is required as the refrigeration package is integral to the package nit/condensing unit which is generally located outdoors. Evaporator units are generally located indoors. The local systems are smaller in size and are less bulky.
Aesthetics	Central systems are generally designed as concealed systems and the visible distribution grilles etc can be easily blended with the aesthetics.	The appearance of local units can be unappealing and may not necessarily blend well with the aesthetics.
Zoning	Central HVAC system may serve multiple thermal zones and have their major components located outside the zone(s) being served, usually in some convenient central location.	A local HVAC system typically serves a single thermal zone and has its major components located within the zone itself or directly adjacent to the zone. Multiple units are required for multiple zones.
Controls	Central HVAC systems will a control point for each thermal zones. The controls are field wired and are integrated to central control panel. The controls are complex and depend on the type of system. Constant air volume (CAV) systems alter the temperature while keeping the constant air delivery. CAV systems serving multiple zones rely on reheat coils to control the delivered cooling. This incurs lot of energy wastage due to simultaneous cooling and heating. Space temperature control can also be achieved by applying a variable air volume (VAV) system, which primarily alters the air delivery rates. The VAV system may or may not have a reheat coil, which provides additional heat when the space does not need to be cooled or needs less cooling than would be delivered by supply air at the terminal box's minimum air quantity setting.	Local units are off shelf items complete with integrated controls. They usually have a single control point which is typically only a thermostat. The room-by-room or "zone" Control minimizes overcooling typical of central air-conditioning systems. With the zone-control ability of the compact systems, only occupied spaces are maintained at a comfort level, and conditioning for the rest of the building is turned down or shut off.
Air Quality	The quality of air conditioning is comparatively superior, with better control over temperature, relative humidity, air filtration and air distribution. Best suited for applications demanding close control of temperature, humidity and cleanliness and can be customized as per the design conditions	The air quality is not comparable to central systems. These systems typically cannot provide close humidity control or high efficiency filtration. The compact systems, being standard factory items, typically cannot be modified to suit the required design conditions all the times.
Efficiency	Central systems usually operate under part load conditions, and localized areas cannot be isolated for complete shut down under any condition. In a central system, the individual control option is not always available. If individual control is desired, the system shall be designed as variable air volume system (VAV) with localized thermostats.	In a building where a large number of spaces may be unoccupied at any given time, such as a dormitory or a motel, local systems may be totally shut off in the unused spaces, thus providing huge energy saving potential. As a self-contained system, a local HVAC system may provide greater occupant comfort through totally individualized control options -- if one room needs heating while an

	CENTRAL SYSTEMS	LOCAL SYSTEMS
	Central systems designed for VAV system is based on block load calculations, as the VAV units allow the system to borrow air from areas with low load. By incorporating VAVs with variable speed drive on air handling units, it is possible to achieve excellent savings in power.	adjacent one needs cooling, two local systems can respond without conflict The compact systems being small are designed for full peak load and the standard rooftop or package units are not typically available with variable speed option.
Operations and Maintenance (O&M)	Large central systems have life expectancy of 20 to 25 years. Central systems allow major equipment components to be kept isolated in a mechanical room. Grouping and isolating key operating components allows maintenance to occur with limited disruption to building functions.	Local systems have life expectancies of 15 years or less. Local systems maintenance may often be relatively simple but such maintenance may have to occur directly in occupied spaces.
Monitoring	Central systems do not provide flexibility of individual energy metering very easily. Central systems are amenable to centralized energy management control schemes and the building management systems (BMS).	The energy utilization of local compact units can be simply measured by installing a local energy meter with each unit. Local system units cannot be easily connected together to permit centralized energy management operations. Local systems can be integrated to BMS with respect to on-off functions through electric circuit control, but more sophisticated central control (such as night-setback or economizer operation) is not possible.
Cost	The initial purchasing and installation cost of a central air conditioning system is much higher than a local system. These systems can offer higher system efficiencies (full load and part load) and thus, can pay pack the elevated initial costs through reduced costs of operations within a few years. Extra cost benefits can be achieved due to the potential for energy efficiency measures like thermal heat recovery, economizers, energy storage systems and etc.	Packaged and split units have much lower first costs than a central system. The operating costs of unitary systems is usually higher due to lower efficiency ratings and lower part load performance values The potential for adoption of high-tech energy efficiency measures is very limited

Source: A. Bhatia, Course Content (PDH 149), HVAC Design Aspects: Choosing A Right System - Central V/s Compact Systems. http://www.pdhcenter.com/Heating System Types

Heating system types can be classified fairly well by the heating equipment type. The heating equipment used in Indian commercial buildings includes boilers (oil and gas), furnaces (oil, gas, and electric), heat pumps, and space heaters.

Boiler-based heating systems have steam and/or water piping to distribute heat. Boilers can be self-contained unit, or they can be packaged units which are factory-built systems, disassembled for shipment, and reassembled at the site. The heated water may serve preheat coils in air handling units; reheat coils, and local radiators. Systems that circulate water or a fluid are called hydronic systems. Additional uses for the heating water are for heating of service water and other process needs, depending on the building type. Some central systems have steam boilers rather than hot water boilers because of the need for steam for conditioning needs (humidifiers in air-handling units) or process needs (sterilizers in hospitals, direct-injection heating in laundries and dishwashers, etc.).The remaining heating systems include heat pumps and space heaters that heat directly and require little or no distribution.

HVAC Equipment Efficiency Measurements

The cooling efficiency for air conditioners is rated as the 'Cooling Load' in kW/ton for larger machines and 'Energy Efficiency Ratio (EER) or 'Coefficient of Performance

(COP) is rated for smaller machines. Similarly, in heating modes the 'Heating Season Performance Factor' (HSPF) and the 'Annual Fuel Utilization Efficiency' (AFUE) measures the efficiencies for heat pumps and gas furnaces/boilers respectively.

Cooling Load is defined as the ratio of energy consumption in *kW* to the rate of heat removal in *tons* at the rated condition. The lower the *kW/ton,* the more efficient is the system.

The 'Coefficient of Performance' (COP) - is the ratio between useful energy acquired and energy applied and can be expressed as:

$COP = E_u / E_a$ where

COP = coefficient of performance

E_u = useful energy acquired

E_a = energy applied

COP can be used to define both cooling efficiencies and heating efficiencies as for heat pumps. Cooling *COP* is defined as the ratio of heat removal to energy input to the compressor. Heating *COP* is defined as the ratio of heat delivered to energy input to the compressor. *COP* can be used to define the efficiency at single standard or non-standard rated conditions, or as a weighted average of seasonal conditions. The term may or may not include the energy consumption of auxiliary systems such as indoor or outdoor fans, chilled water pumps, or cooling tower systems. The higher the *COP,* the more efficient is the system. *COP* can be treated as an efficiency where *COP* of *2.00 = 200%* efficiency. For unitary heat pumps, ratings at two standard outdoor temperatures of *8.3°C* and *-8.3°C* are typically used.

Energy Efficiency Ratio - EER

The 'Energy Efficiency Ratio' *(EER)* - is a term generally used to define cooling efficiencies of unitary air-conditioning and heat pump systems. The efficiency is determined at a single rated condition specified by an appropriate equipment standard and is defined as the ratio of net cooling capacity - or heat removed in *Btu/h* - to the total input rate of electric energy applied - in *watt hour*. The units of *EER* are *Btu/Wh*.

$EER = E_c / P_a$ where

EER = energy efficient ratio (Btu/Wh)

E_c = net cooling capacity (Btu/h)

P_a = applied energy (Watts)

This efficiency term typically includes the energy requirement of auxiliary systems such as the indoor and outdoor fans. A higher EER indicates a more efficient system. Often, efficiencies are measured by the 'Seasonal Energy Efficiency Ratio' (SEER), which indicates how efficiently a residential central cooling system (air conditioner or heat pump) will operate over an entire cooling season, as opposed to a single outdoor temperature. As with EER, a higher SEER reflects a more efficient cooling system. SEER is calculated based on the total amount of cooling (in Btu) the system will provide over the entire season divided by the total number of watt-hours it will consume.

Cooling eefficiencies are measured at peak load and at 'Integrated Part Load Value' (IPLV). The IPLV measures the efficiency of air conditioners under a variety of conditions -- that is, when the unit is operating at 25%, 50%, 75% and 100% of capacity and at different temperatures. The concept of the "most efficient chiller" makes sense only in context of the facility to be cooled. If a chiller operates 90% of the time at 60% load and very rarely at 90-100 % load, then the most efficient chiller for that application is the one with the lowest kW/ton at 60% load, regardless of peak load kW/ton.

The 'Heating Seasonal Performance Factor' (HSPF) is the measurement of how efficiently all residential and some commercial heat pumps will operate in their heating mode over an entire normal heating season. The higher the HSPF, the more efficient is the system. HSPF is determined by dividing the total number of Btu of heat produced over the heating season by the total number of watt-hours of electricity that is required to produce that heat.

The 'Annual Fuel Utilization Efficiency' (AFUE) is the measurement of how efficiently a gas furnace or boiler will operate over an entire heating season. The AFUE is expressed as a percentage of the amount of energy consumed by the system that is actually converted to useful heat. For instance, a 90% AFUE means that for every Btu worth of gas used over the heating season, the system will provide 0.9 Btu of heat. The higher the AFUE, the more efficient is the system.

FAQs 6: Air Handling Unit Concepts

What is an Air Handler?

An air handler is responsible for moving air throughout the duct work in an air conditioning system. All air handlers contain a blower motor and squirrel cage blower housing which facilitates the movement of air. Most air handlers also include system controls, which are connected to the thermostat. Depending on the type of system, an air handler can also be integrated with a gas, oil, electric furnace, heat pump, and cooling coils (or evaporator coil for the air conditioning).

High-efficiency air distribution systems can substantially reduce fan power required by an HVAC system, resulting in dramatic energy savings. The largest gains in efficiency for air distribution systems are realized in the system design phase for new constructions or major retrofit projects. Passive or natural air transport systems have the highest efficiency, and successful, modern examples of this approach are steadily accumulating. For buildings that require mechanical ventilation, innovative design approaches and a methodical examination of the entire air system can greatly improve efficiency and effectiveness.

Air-handling efficiency The energy required to move air is calculated as follows:

$$Energy = \frac{Flow * Pressure * Duty\ Factor}{Efficiency}$$

All four of these factors can be manipulated to reduce the energy consumption of the system. Air flow has a dominant effect on energy consumption because it shows up twice in the energy equation: as the first term and as a squared function in the second term (pressure). The pressure a fan must work against depends on two primary factors: the flow and duct design features such as diameter, length, surface treatment, and impediments such as elbows, filters, and coils. Typical pressure losses are on the order of 2 to 6 inches water gauge (wg); an efficient system operates at less than 1.5" wg. A fan's duty factor is the number of hours per year that it operates, sometimes presented as a percentage. Many large fans spin at full speed continuously (8,760 hours per year). Using simple or complex controls, duty factors can often be reduced to about 3,000 hours per year or less by limiting fan operation to occupied periods. The mechanical efficiency of the fan and its drive system can typically be raised from the 40 to 60% range to the mid-80 % range.

Design options for improving air distribution efficiency include:

- Variable-air-volume (VAV) systems
- VAV diffusers
- Low-pressure-drop duct design

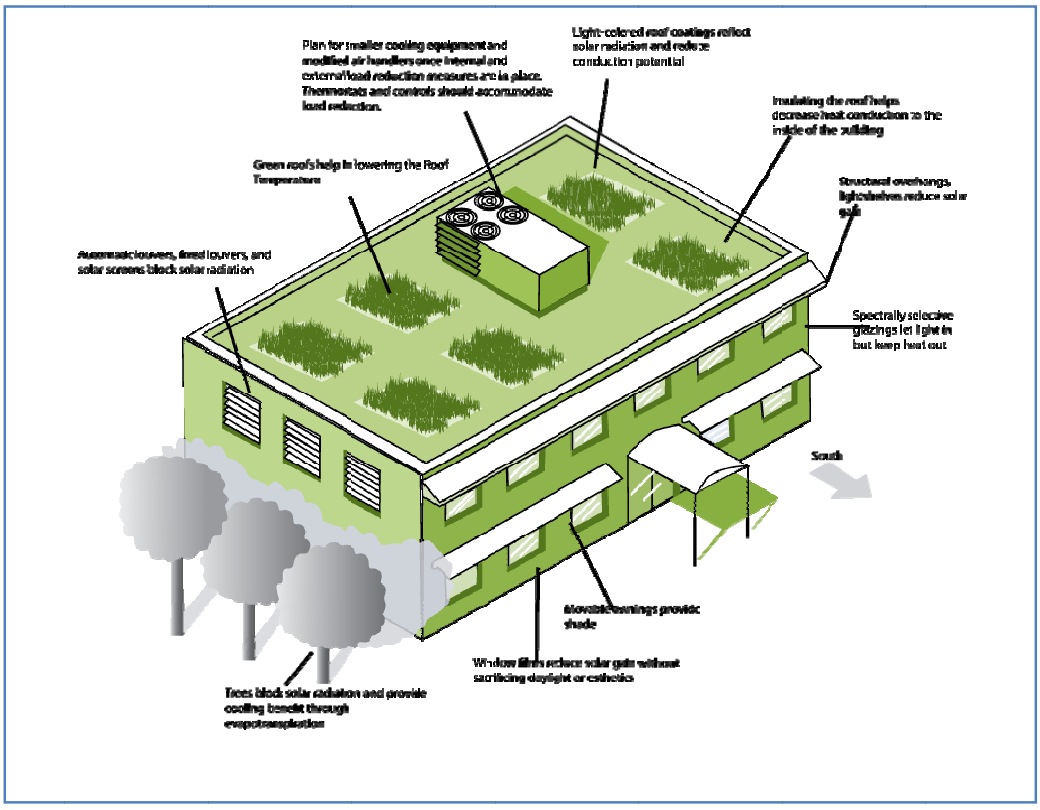
- Low-face-velocity air handlers
- Fan sizing and variable-frequency-drive (VFD) motors
- Displacement ventilation systems.

Energy Efficient HVAC Design

As the climate map of India shows (Appendix E, ECBC), most of India falls mainly under three climatic zones (hot-dry, warm-humid and composite) requiring the cooling of buildings for almost 6-8 months to provide thermal comfort to the occupants. All of this comes with significant energy consumption and costs. Both need to be addressed while designing any building.

The overall capacity, system type and energy performance of HVAC systems depend to a large extend on the overall cooling load of the building. The first step towards a Whole Building Design approach for creating an energy efficient system would be to reduce the cooling load by controlling unwanted heat gain in the building. As shown in Figure 14, external heat gains can be avoided with architectural form, light-colored building surfaces, vegetation, high performance glazing, etc. Internal heat gains can be reduced by using more efficient building equipment (such as lights, computers, printers, copiers, servers) and direct venting of spot heat sources.

Figure 14: Cooling Load Reduction Measures


Plan for smaller cooling equipment and modified air handlers once internal and external load reduction measures are in place. Thermostats and controls should accommodate load reduction.
Light-colored roof coatings reflect solar radiation and reduce conduction potential
Insulating the roof helps decrease heat conduction to the inside of the building
Green roofs help in lowering the Roof Temperature
Structural overhangs, light shelves reduce solar gain
Automatic louvers, fixed louvers, and solar screens block solar radiation
Spectrally selective glazings let light in but keep heat out
South
Trees block solar radiation and provide cooling benefit through evapotranspiration

Source: E Source Cooling Atlas

Huge savings are available from reducing the velocity, pressure, and friction losses in ducts and piping. Light commercial buildings typically use constant air-volume rooftop HVAC units, applying the same ductwork and installation techniques found in residential systems. They are generally "un-engineered" systems leading to short cuts in construction practices and/or the use of lower-grade materials to deliver a project within budget. In the case of ductwork, this shows up as sloppy connections, inexpensive leaky diffusers, and low-grade duct tapes. With respect to the HVAC equipment, this leads to installations and service techniques that produce degraded

equipment performance. The ECBC contains requirements for duct insulation and hydronic piping insulation that minimize distribution losses. Additional improvement can be captured with high-efficiency fans, diffusers, and other components.

The use of non vapor-compression cooling techniques can help save 20-30% energy per unit of cooling as conventional cooling equipment. These alternatives include natural ventilation with cool outside air, ground coupled cooling, night sky cooling, evaporative cooling, absorption cooling, and desiccant systems fuelled by natural gas, waste heat, or solar energy. High efficiency chillers, pumps, and fans, multiplexed chillers (to minimize part-load operation penalties), large heat exchangers, low-friction duct layout and sizing, low pressure drops in air-handling and piping components, and overall optimization of the entire HVAC system will further help in making the system more efficient (see Table 17). Finally, the overall system performance can be enhanced by improving the HVAC controls by use of better algorithms, sensors, signal delivery, user interface, simulators, and other measures.

Table 17: Energy Savings Potential in HVAC System Designs

Component	Cooling Load (kW/ton)		Improvement Potential (%)
	Conventional Design	Optimized Design	
Chiller	0.75	0.50	33%
Air Distribution System	0.60	0.06	90%
Water Pump	0.30	0.04	87%
Cooling Tower	0.10	0.02	80%
Total	1.75	0.62	65%

ECBC Requirements

ECBC includes provisions for most HVAC system types. All cooling equipment is required to meet or exceed minimum efficiency requirements in the ECBC 5.2.2. Systems not included are referred to ASHRAE 90.1 – 2004. Single zone unitary systems are covered as well as multiple zone air and water systems. The more complex the system, the more requirements apply to that system: a single-zone unitary system has fewer requirements than a complex system made up of chillers, boilers, and fan coil units. For natural ventilation requirements, buildings are required to follow the design guidelines provided for natural ventilation in the National Building Code of India, 2005 [ECBC 5.2.1].

Unless following the Whole Building Performance approach for compliance, the HVAC system must follow both the mandatory requirements described in ECBC Section 5.2 and the prescriptive requirements described in ECBC Section 5.3. ALL buildings must follow the mandatory requirements.

5.2 MANDATORY REQUIREMENTS

The ECBC contains mandatory requirements for the following elements of the HVAC system:

- Equipment efficiency
- Controls
- Duct insulation,
- Hydronic piping insulation
- Condensers
- System balancing.

FAQs 7: HVAC

What are the most important elements of an efficient HVAC system?

There are four elements:

- The duct system must have a good design that is planned early in the construction process and understood by the builder, framer, structural engineer and designer. Every fit and bend in the duct system affects the efficiency of the system.
- The system must be properly installed with the correct amount of airflow and refrigerant charge.
- The system must be appropriately sized according to industry standards.
- There must be easy access to the coil for maintenance.

What are other important criteria that will aid in my selection decision?

Effectiveness	Durability	Lifetime (years)
Space requirements	Noise	Water consumption
Control capacity	Thermal comfort	Multi-zone capacity
Natural ventilation	Indoor air quality	

Does it cost more to install higher efficiency equipment?

The initial capital cost is often higher, but there are other costs to consider in addition to first cost. Maintenance costs, energy operating cost and lifecycle cost will all be lower with more efficient equipment.

Is a bigger HVAC system better at handling peak loads?

Proper sizing of the system is critical to both energy efficiency and cost effectiveness. Over-sizing the system is unnecessary. The compressors in oversized packaged air conditioners or heat pumps cycle frequently and overall efficiency drops with each cycle. Frequent cycling also reduces the efficiency of boilers, furnaces, and many other types of equipment.

Do daylighting features impact HVAC equipment sizing?

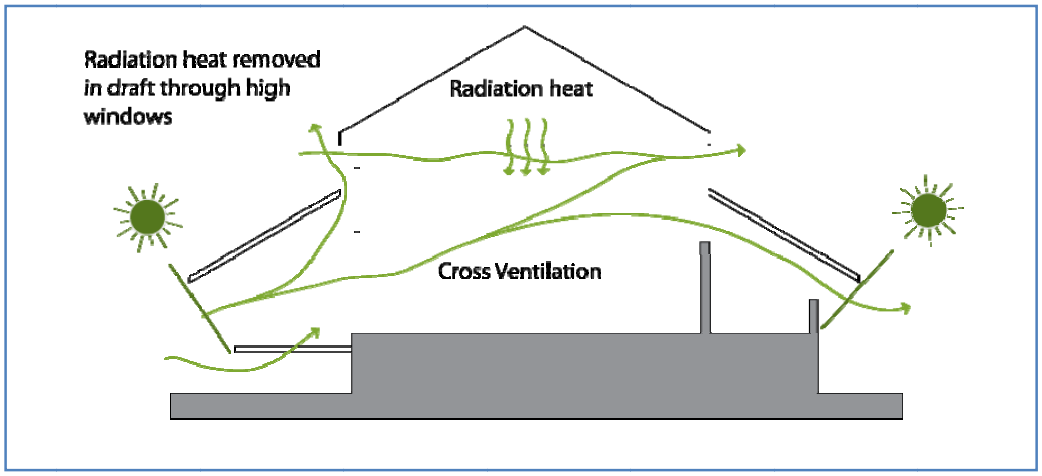
Yes. Daylighting contributes less heat than electrical lighting. With properly designed daylighting, air conditioning equipment can be downsized, saving money on equipment costs and lower energy usage.

5.2.1 Natural Ventilation

For ventilation requirements, buildings must follow the design guidelines provided for natural ventilation in the National Building Code of India 2005, Part 8, 5.4.3 and 5.7.1 [ECBC 5.2.1].

Ventilation can not only provide fresh air that improves the indoor air quality, but an effective design incorporating passive solar elements can be effective and reducing the cooling loads on the HVAC system, as seen in Figure 15 below.

Figure 15: Cross Ventilation Schematic



5.2.2 Minimum Equipment Efficiencies

A wide range of efficiencies are available for HVAC system components. Minimum equipment efficiencies are required to be met for all installed equipment including: Unitary Air Conditioning Equipment, Chillers, Heat Pumps Heating Mode, Furnaces, and Boilers. All heating and cooling equipment must meet or exceed the minimum efficiency requirements presented in Section 5 of ECBC. Many of these requirements are based on those developed for the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) Standard 90.1. Any equipment not listed in the tables should refer to the efficiencies in ASHRAE Standard 90.1-2004 Section 6.4.1 for guidance.

The minimum energy performance standards for chillers are presented in Table 21. Selection of individual equipment efficiency should be considered in the context of the whole HVAC system. In a chilled-water system, for example, although the chiller is at the core of the system and typically is the single largest energy user, simply selecting a high-efficiency chiller does not guarantee high performance. Auxiliary equipment (such as fans and blowers) and design decisions (such as "approach temperatures") can have substantial effects on overall efficiency. Thus, attention to overall system design and auxiliary components is critical to achieving optimal performance and comfort. Even in packaged air-conditioning systems, leaky ductwork, improper sizing, refrigerant charge, and air flow rates can considerably affect energy performance.

ECBC 5.2.2 includes Unitary Air Conditioner shall meet IS 1391- Part 1 (Table 18), Split air conditioner shall meet IS 1391 - Part 2 (Table 19), Packaged air conditioner shall meet IS 8148 (Table 19) and Boilers shall meet IS 13980 (the standard specifies the procedure of Boiler to get required energy efficiency that can be equivalent to thermal efficiency mentioned in ECBC) with above 75% thermal efficiency.

Table 18: Power Consumption Ratings for Unitary Air Conditioners- Specification

Rated Cooling Capacity (kcal/h)	Maximum Power Consumption (kW)
1 500	1.1
2 250	1.4
3 000	1.6
3 750	2.0
4 500	2.4
6 000	3.2
7 500	4.25
9 000	5.2

Source: Code No.: IS 1391 (Part-1): 1992

Table 19: Power Consumption Rating for Split Air Conditioner

Rated Cooling Capacity (kcal/h)	Maximum Power Consumption (kW)
3 000	1.7
4 500	2.6
6 000	3.4
7 500	4.5
9 000	5.4

Source: Code No.: IS 13129 (Part-2): 1992

Table 20: Capacity Rating Test for Packaged air Conditioners-Specification

Cooling Capacity		Maximum Power Consumption	
Watts	Tons of Refrigeration	Water Cooled	Air Cooled
10,000	3	3,750	4,750
17,500	5	6,000	7,000
26,250	7.5	9,000	10,000
35,000	10	11,500	13,500
52,000	15	17,000	20,000

Source: Code No.: IS 8148 2003

Table 21: Chillers

Equipment Class	Minimum COP	Minimum IPLV	Test Standard
Air Cooled Chiller <530 kW (<150 tons)	2.90	3.16	ARI 550/590-1998
Air Cooled Chiller ≥530 kW (≥150 tons)	3.05	3.32	ARI 550/590-1998
*Centrifugal Water Cooled Chiller < 530 kW (<150 tons)	5.80	6.09	ARI 550/590-1998
*Centrifugal Water Cooled Chiller ≥530 and <1050 kW (≥150 and <300 tons)	5.80	6.17	ARI 550/590-1998
*Centrifugal Water Cooled Chiller ≥ 1050 kW (≥ 300 tons)	6.30	6.61	ARI 550/590-1998
Reciprocating Compressor, Water Cooled Chiller all sizes	4.20	5.05	ARI 550/590-1998
Rotary Screw and Scroll Compressor, Water Cooled Chiller <530 kW (<150 tons)	4.70	5.49	ARI 550/590-1998
Rotary Screw and Scroll Compressor, Water Cooled Chiller ≥530 and <1050 kW (≥150 and <300 tons)	5.40	6.17	ARI 550/590-1998
Rotary Screw and Scroll Compressor, Water Cooled Chiller ≥ 1050 kW (≥ 300 tons)	5.75	6.43	ARI 550/590-1998

*These are aspirational values. For mandatory values refer to ASHRAE 90.1-2004

5.2.3 Controls

Controls are one of the most critical elements for efficiency of any HVAC system. They give the building manager the ability to operate the system efficiently .Controls determine how HVAC systems operate to meet the design goals of comfort, efficiency, and cost-effective operation. The ECBC requirements specify the use of time clocks, temperature controls/thermostats, and two-speed or variables speed drives for fans.

5.2.3.1 All mechanical cooling and heating systems shall be controlled by a time clock

xxx

5.2.3.2 xxx

5.2.3.3 The other mandatory control requirement is for cooling towers and closed circuit fluid coolers. These must have one of the following to control the fans: two-speed motors, pony motors, or variable speed motors [ECBC 5.2.3.3].

Exceptions

All mechanical cooling systems which are at least 24 kW (8 tons) and heating systems which are at least 7 kW (2 tons) are required to be controlled by a time clock [ECBC 5.2.3.1]. It is further specified that time clocks used have the ability to do the following:

- Control system start/stop for 3 different day-types,
- Retain programming for at least 10 hours during a power loss, and
- Have a manual override that allows temporary operation for 2 hours.

Example 6: Thermostat Compliance

Q: Can a thermostat with set points, determined by sensors (such as a bi-metal sensor encased in a bulb), be used to accomplish a night setback?

A: Yes. The thermostat must have two heating sensors, one each for the occupied and unoccupied temperatures. The controls should allow the setback sensor to override the system shutdown.

If heating and cooling are being supplied by the same unit, they must be interlocked to prevent simultaneous heating and cooling.

Energy and Water Efficiency in Cooling Towers

Water based HVAC systems offer significant energy savings due to the ability of water to transport large quantities of heat over relatively long distances, more efficiently than air-based systems. Additionally, they offer the advantages like smaller equipment size and cost; along with reduced maintenance and extended life of mechanical equipment. However, for water scarce urban centers in India, the viable installation and operation of cooling towers will require balancing needs for energy efficiency and water conservation simultaneously. Given below are some considerations for improving energy and water efficiency of water based cooling towers:

Energy Efficiency Measures:

- Proper site selection and sizing of the tower can reduce fan speed, capacity and sound and help to conserve energy usage
- Centrifugal fans in favor of lower energy axial fans can reduce horsepower by 50% or more for the same capacity
- Fan control through two-speed motors, pony motors, or variable speed motors (ECBC 5.2.3.3)

Water Efficiency Measures:

- An optimized bleed rate for the tower should be maintained to regulate water consumption. The evaporation rate is dependent on the load, which can vary widely and a constant bleed rate usually discharges more water than required. A properly operating conductivity meter can automatically control bleed to the proper amount required to maintain the desired tower chemistry in the system at all times.
- Contaminant induction should be minimized and a proper blow down rate should be maintained. Water treatment regimens are effective for water conservation, keeping the cooling loop cleaner, saving energy, reducing maintenance, and improving reliability of the entire cooling system.
- New technological solutions like hybrid wet-dry cooling tower designs, which combine wet and dry cooling can be adopted to reduce water use, some as much as 70% compared to conventional towers. Typically, a dry finned coil section is combined in series with an evaporative section in these units. The dry finned section handles as much of the load as possible, with the unit able to operate completely dry at reduced ambient. Both open and closed circuit versions are available.

Source: Morrison F.: What's up with Cooling Tower (2004). ASHRAE Journal 46 (7)

Many electric motor-driven devices operate at full speed even when the loads they are serving are at partial capacity. Motors with multiple speed capability can match the output of the device to the load to save energy. Variable frequency drive (VFD) motors are one of the most effective options. VFDs accomplish part load control by varying electric motor speed and commonly save 50 percent, or more, energy over other part load control strategies.

FAQ 8: What is a Variable Speed Drive?

A variable speed drive (VSD) is an electronic device that controls the rotational speed of a piece of motor-driven equipment (e.g. a blower, compressor, fan, or pump). Speed control is obtained by adjusting the frequency of the voltage applied to the motor. This approach usually saves energy for variable-load applications.

5.2.4 Piping and Ductwork

5.2.4.1 Pipe Insulation

To minimize standby losses, the ECBC requires that pipelines for the entire hot water system, including the storage tanks, must be insulated. The required R-value for heating and cooling systems is based on the operating temperature of the system, as shown in the tables below:

Insulation

Piping insulation exposed to weather is required to be protected by aluminum sheet metal, painted canvas, or plastic cover. Cellular foam insulation must also be protected in this manner, or be painted with water retardant paint [*ECBC 5.2.4.1*]. Ductwork should also be protected in the same manner. Condensing moisture can cause many types of insulation, such as fiberglass, to lose their insulating properties or degrade.

Insulating ducts in unconditioned spaces and outside the building is the first portion of the duct requirements within the ECBC. The R-value is measured on a horizontal plane in accordance with ASTM C518 at a mean temperature of 24 °C (75 °F) at the installed thickness. All insulation values are shown on ECBC Table 5.2 (reproduced below in Table 22). A list of some typical material meeting or exceeding the recommended R-values is shown inTable 233.

All supply ductwork located outside the building must be insulated to a minimum R-1.4 (R-8) value. This would include, for example, a duct located on top of a flat roof. This required R-value also applies to insulation for ductwork located either unventilated attics with no roof insulation or in ventilated attics. Return ducts in these three conditions must have R-0.6 (R-3.5) insulation.

Supply ducts installed in attics with roof insulation are required to be insulated with a lower minimum R-value – R-0.6 (R-3.5), as are ducts in interior unconditioned spaces, such as both ventilated and non-ventilated crawlspaces. Supply ducts which are buried must also have R-0.6 (R-3.5) insulation). The return ducts in these three cases are not required to be insulated.

Any ductwork in indirectly conditioned space, such as return air plenums with or without exposed roofs above, is not required to be insulated. Of course, ductwork in conditioned space also has no insulation requirement. Although not always aesthetically possible, locating ductwork within conditioned space is an excellent efficiency strategy since this eliminates undesired heating or cooling of the air in the ducts.

Table 22: Ductwork Insulation

	Required Insulation[0 below]	
Duct Location	Supply Ducts	Return Ducts
Exterior	R-1.4	R- 0.6
Ventilated Attic	R-1.4	R- 0.6
Unventilated Attic without Roof Insulation	R-1.4	R- 0.6
Unventilated Attic with Roof Insulation	R- 0.6	No Requirement
Unconditioned Space[0 below]	R- 0.6	No Requirement
Indirectly Conditioned Space[0 below]	No Requirement	No Requirement
Buried	R- 0.6	No Requirement
Insulation R-value is measured on a horizontal plane in accordance with ASTM C518 at a mean temperature of 24°C (75°F) at the installed thickness Includes crawlspaces, both ventilated and non-ventilated Includes return air plenums with or without exposed roofs above.		

Table 23: Sample R-Values for Duct Insulation Materials

Installed R-value1 (h x oF x ft2)/Btu	Typical Material meeting or exceeding the given R-value2
1.9	½ in. Mineral fiber duct liner per ASTM C 1071, Type 1 1 in. Mineral fiber duct wrap per ASTM C 1290
3.5	1 in. Mineral fiber duct liner per ASTM C 1071, Types I & II 1 in. Mineral fiber board per ASTM C 612, Types IA & IB 1 in. Mineral fiber duct board per UL 181 1 ½ in. Mineral fiber duct wrap per ASTM C 1290 1 in. Insulated flex duct per UL 181
6.0	1 ½ in. Mineral fiber duct liner per ASTM C1071, Types I & II 1 ½ in. Mineral fiber duct board per UL 181 1 ½ in. Mineral fiber board per ASTM C 612, Types IA & IB 2 in., 2 lb/ft3 Mineral fiber duct wrap per ASTM C 1290 2 ½ in., 0.6 to 1 lb./ft3 Mineral fiber duct wrap per ASTM C 1290 2 ½ in. Insulated flex duct per UL 181
8.0	2 in. Mineral fiber duct liner per ASTM C 1071, Types I & II 2 in. Mineral fiber duct board per UL 181 2 in. Mineral fiber board per ASTM C 612, Types IA & IB 3 in., ¾ lb/ft3 Mineral fiber duct wrap insulation per ASTM C 1290 3 in. Insulated flex duct per UL 181
10.0	2 ½ in. Mineral fiber board per ASTM C 612, Types IA & IB

Source: ASHRAE 90.1 User Manual (2007), Table 6-D

5.2.4.2 Duct Sealing

Duct sealing is critical to avoid air leaks that prevent the HVAC system from functioning as designed and operated. The ECBC currently does not provide any guidance on ductwork sealing. The ASHRAE 90.1 energy code can be referred to for appropriate seal levels for all ductwork in order to minimize energy losses from the HVAC system. ASHRAE 90.1 tables 6.2.4.3 A and 6.2.4.3 B specify sealing requirements based on the duct location, static pressure classification, and type of the duct (exhaust or return) (Table 24).

Table 24: Ductwork Sealing

Minimum Duct Seal Level

ASHRAE 90.1 Table 6.2.4.3A

Duct Location	Duct Type			
	Supply		Exhaust	Return
	≤ 2 in. w.c.	> 2 in. w.c.		
Outdoors	A	A	C	A
Unconditioned Spaces	B	A	C	B
Conditioned Spaces * *	C	B	B	C

Duct Seal Levels

ASHRAE 90.1 Table 6.2.4.3B

Seal Level	Sealing Requirements *
A	All transverse joints and longitudinal seams, and duct wall penetrations. Pressure-sensitive tape shall not be used as the primary sealant.
B	All transverse joints and longitudinal seams. Pressure-sensitive tape shall not be used as the primary sealant.
C	Transverse joints only

FAQs 9: Duct

What are the most important elements of an efficient duct system?

Ducts are tubes that make up a system to distribute heated or cooled air to various rooms throughout a house. There are six elements:

- The duct system must have a good design that is planned early in the construction process and understood by the builder, framer, structural engineer and designer. Every fit and bend in the duct system affects the efficiency of the system.
- The duct system must be properly installed with the correct amount of airflow and refrigerant.
- The distribution system must be appropriately sized.
- There must be easy access to the coil for maintenance.
- The duct system must be sealed for air leaks.
- The duct system must be insulated.

What is Duct Leakage?

Duct leakage generally refers to holes or unsealed, or unfastened, seams in air ducts and is typically described in any of three different ways: 1) as the fraction of the flow through the HVAC equipment that is lost, 2) as an equivalent hole size, and 3) as a leakage flow at some reference pressure, with the latter two often being normalized by either the surface area of the ductwork or the conditioned floor space.

What are "Sealed Ducts"?

Sealed ducts have appropriately installed joints and connections to minimize leakage of conditioned air. Air leakage cannot be seen by the naked eye, therefore, diagnostic testing is needed to verify leakage and, by using complying tapes, mastics and mechanical fasteners or aerosol sealant, leaks can be closed.

Are insulated ducts the same as sealed ducts?

No, insulated ducts are not necessarily sealed ducts. Care should be taken by the installer to seal the ducts prior to insulation.

5.2.5 System Balancing

5.2.5.1 General

System balancing is a process for measuring the performance of a HVAC system, and for providing the occupants with a comfortably conditioned space. Balancing the air or water based HVAC system of buildings will make it more energy efficient, provide improved thermal comfort, extend the life of the building equipment and reduce the cost of operating it. Balancing is achieved by optimizing the air/water distribution rates for the HVAC system.

Air System Balancing: Adjusting airflow rates through air distribution system devices, such as fans and diffusers, by manually adjusting the position of dampers, splitter vanes, extractors, etc., or by using automatic control devices, such as constant air volume or variable air volume boxes.

Hydronic System Balancing: Adjusting water flow rates through hydronic distribution system devices, such as pumps and coils, by manually adjusting the position of valves, or by using automatic control devices, such as flow control valves.

The ECBC requirements do not dictate a specific way in achieve a balanced HVAC system, but they do require that all systems be balanced in accordance with generally accepted engineering standards. In turn, the construction documents must require that a written balance report be provided to the owner, or the designated representative of the building owner, for HVAC systems serving zones with a total conditioned area exceeding 500 m2 (5,000 ft2). [ECBC 5.2.5.1] Specific strategies for balancing air systems and hydronic systems are also required to be followed, as described below.

FAQ 10: System Balancing

What does it mean when a system is balanced?

When something is balanced, it is even on both sides; everything is equal. Therefore, a balanced hydronic system is one that delivers even flow to all of the devices on that piping system. Each component has an effective equal length of pipe on the supply and return. And when a system is balanced, all of the pressure drops are correct for the devices. When that happens, you have the highest efficiencies possible in that system. You do not need to change your system supply temperatures to accommodate one zone only. The system has the least amount of pressure drop possible, which translates into reduced pumping costs. A balanced hydronic system is one that is efficient. If you have a system that is not delivering

5.2.5.1.1 Air Systems

Balancing is necessary to verify that each space served by a system receives the air volume designed for that space. A means for air balancing should be installed at each supply air outlet and zone terminal device. This includes balancing dampers or other means of supply-air adjustment provided in the branch ducts or at each individual duct register, grille, or diffuser. Installation in the duct system of all devices used for balancing, shown on the approved mechanical plans, typically, on the ductwork layout, should be verified. The requirements state that air systems must first be balanced in a manner to minimize throttling losses. For fans greater than 0.75 KW (1.0 HP), fans must then be adjusted to meet design flow conditions. [ECBC 5.2.5.1.1]

5.2.5.1.2 Hydronic Systems

These systems must also be proportionately balanced in a manner to first minimize throttling losses. Further action is required if pump motors are greater than 7.5 KW (10 HP) and throttling results in greater than 5% of the nameplate KW or HP draw, or 2.2 KW (3 HP). In these cases, either the pump impeller must be trimmed or the pump speed adjusted to meet the design flow conditions.

System Balancing

Construction documents provide vital information the building owner on how to properly operate and maintain a system that has been properly balanced. Verify during final inspection that an *operations manual* has been passed on to the building owner and that it contains the following information at a minimum:

- HVAC equipment capacity
- Equipment operation and maintenance manuals
- HVAC system control maintenance and calibration information, including wiring diagrams, schedules, and control sequence descriptions.
- A complete written narrative of how each system is intended to operate.

Pump heads often are oversized to assure terminal flow rates. A 10% to 100% safety factor is frequently added to compensate for higher than planned head loss equipment, or for unexpected piping changes. But a 100% head safety factor, for example, increases power requirements by approximately 2.5 times, depending on pump curve characteristics (flat or steep). *Proportional balancing* (impeller trimming) can eliminate unnecessary power consumption.

5.2.6 Condensers

5.2.6.1 Condenser Locations

A condenser is a heat exchanger designed to liquefy refrigerant vapor through heat removal. The typical condensing unit houses a compressor, a condenser fan motor, and coils, along with controls which make all the components work sequentially. These units range from a half a ton for a small "mini-split" system, all the way up to several hundred tons for roof-top units serving a large commercial building. Without the condenser in refrigeration systems, it would not be possible to reject the heat which the air handler and evaporator coil portion of the refrigeration system are responsible for absorbing.

The ECBC regulates condensers by specifying that they be located in as cool an environment as possible to facilitate efficient operation. Condensers should be located so that the heat discharge of other adjacent equipment does not interfere with the heat sink. The condenser should also not interfere with other systems installed nearby. [ECBC 5.2.6.1]

In addition, all centralized cooling water system used in high-rise buildings must use soft water for the condenser and chilled water system. [ECBC 5.2.6.2]

5.2.6.2 Treated Water for Condensers

FAQs 11: Condenser

What is a Chiller?

A chiller is essentially a packaged vapor compression cooling machine. The chiller rejects heat either to condenser water (in the case of a water-cooled chiller) or to ambient air (in the case of an air-cooled chiller). Water-cooled chillers incorporate the use of cooling towers, which improve heat rejection more efficiently at the condenser than air-cooled chillers. For a water-cooled chiller, the cooling tower rejects heat to the environment through direct heat exchange between the condenser water and cooling air. For an air-cooled chiller, condenser fans move air through a condenser coil. As heat loads increase, water-cooled chillers are more energy efficient than air-cooled chillers. A typical chiller is rated between 15 to 1000 tons (53 to 3,500 kW) in cooling power.

What are the different types of chillers?

Chillers are classified according to compressor type. Electric chillers for commercial comfort cooling have centrifugal, screw, scroll, or reciprocating compressors. Centrifugal and screw chillers have one or two compressors. Scroll and reciprocating chillers are built with multiple, smaller compressors.

- Centrifugal chillers are the quiet, efficient, and reliable workhorses of comfort cooling. Although centrifugal chillers are available as small as 70 tons, most are 300 tons or larger.
- Screw chillers are up to 40% smaller and lighter than centrifugal chillers, so are becoming popular as replacement chillers.
- Scroll compressors are rotary positive-displacement machines, also fairly new to the comfort cooling market. These small compressors are efficient, quiet, and reliable. Scroll compressors are made in sizes of 1.5 to 15 tons.

Why must my chilled water system use softened water?

The ECBC requires condenser water treatment to eliminate mineral buildup (*ECBC Section 5.2.6.2*). Mineral deposits create poor heat transfer situations reducing the efficiency of the unit.

5.3 PRESCRIPTIVE REQUIREMENTS

ECBC prescriptive requirements apply only if the HVAC system in the building meets the following criteria:

The system serves a single zone:

- If the system provides cooling, it is through a unitary packaged or split-system air conditioner, or heat pump
- If the system provides heating, it is through a unitary packaged or split-system heat pump, fuel-fired furnace, electric resistance heater, or baseboards connected to a boiler
- The outside air quality is less than 1,400 l/s (3,000 cfm) and less than 70% of supply air at design conditions

If the system meets all of the above conditions, then the system must comply with prescriptive requirements for economizers and variable flow hydronic systems (sections 5.3.1 and 5.3.2). If not, then the users can get useful guidance from ASHRAE 90.1-2004, Section 6.5.

FAQs 12: Prescriptive Requirements

What is a zone for a HVAC system?

A space or group of spaces within a building with heating and cooling requirements that are sufficiently similar so that desired conditions (e.g., temperature) can be maintained throughout using a single sensor (e.g., thermostat or temperature sensor).

What is a Heat Pump?

A heat pump consists of one or more factory-made assemblies that normally include indoor conditioning coil, compressor, and outdoor coil, including means to provide a heating function. Heat pumps provide the function of air heating with controlled temperature, and may include the functions of air cooling.

5.3.1 Economizers

An economizer is simply a collection of dampers, sensors, actuators, and logic devices that together decide how much outside air to bring into a building (See Figure 17). Economizers allow the use of outdoor air to cool the building when the outside temperature is cooler than that inside. Under the right conditions, sensors and controls will shut down the compressor and bring in the outside air through the economizer louvers. This saves energy by eliminating unnecessary cooling. A properly operating economizer can cut energy costs by as much as 10 percent of a building's total energy consumption, depending mostly on local climate and internal cooling loads.

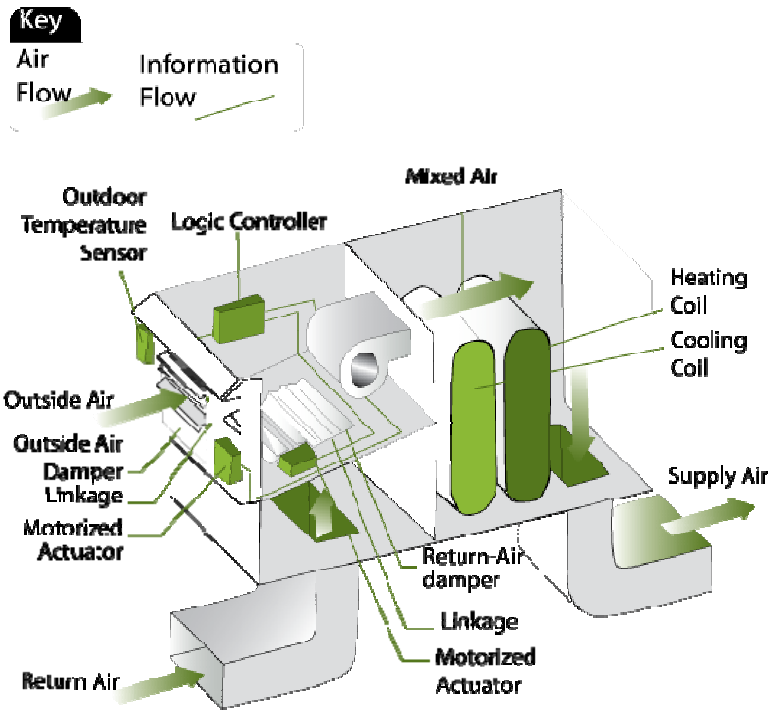
5.3.1.1 Air and water-side economizers

The ECBC requires each individual cooling fan system that has a design supply capacity over 1,200 l/s (2,500 cfm) and a total mechanical cooling capacity over 22 kW (6.3 tons) to include either an air or water economizer.

Where an air economizer is used, it must be capable of modulating outside-air and return-air dampers to supply 100 percent of the design supply air quantity as outside-air.

When a water economizer is used, it must be capable of providing 100% of the expected system cooling load at outside air temperatures of 10°C (50°F) dry bulb/7.2°C (45°F) wet bulb and below. In other words, under the right conditions, an economizer must be able to switch a system over so that all of the design supply air is supplied by outside air.

Figure 16 The Components of an Economizer



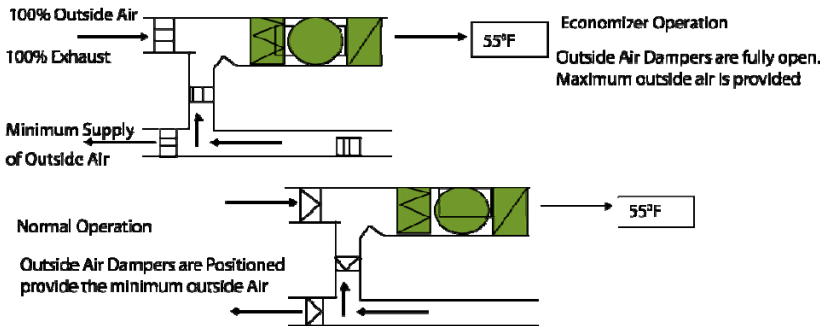
Source: E Source Cooling Atlas

FAQs 13: Air Economizer

What is an Air Economizer?

An air economizer is duct and damper arrangement and automatic control system that together allow a cooling system to supply outdoor air to reduce or eliminate the need for mechanical cooling during mild or cold weather.

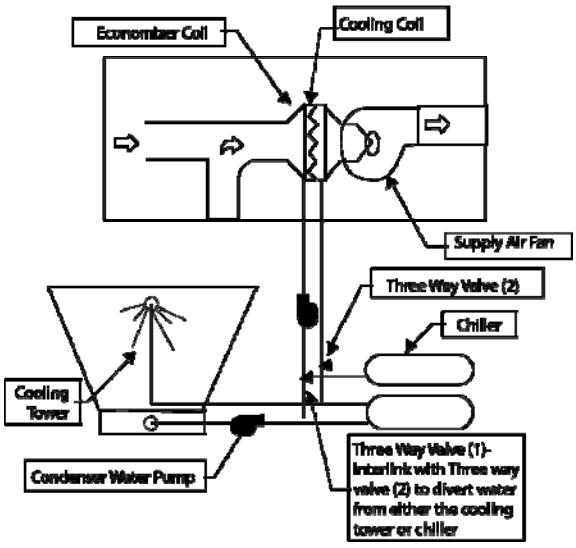
Air-Supply Economizer Diagram



What is a Water Economizer?

A water economizer is a system by which the supply air of a cooling system is cooled indirectly with water that is itself cooled by heat or mass transfer to the environment without the use of mechanical cooling.

Water-Supply Economizer Diagram


Economizer Coil
Cooling Coil
Supply Air Fan
Three Way Valve (2)
Chiller
Cooling Tower
Condenser Water Pump
Three Way Valve (1)- Interlink with Three way valve (2) to divert water from either the cooling tower or chiller

Can I take advantage of cool outside air to pre-cool my building?

Yes, use the buildings intrinsic thermal mass to reduce peak cooling loads by circulating cool nighttime air to pre-cool the building prior to daily occupancy in the cooling season. The building control system can operate ventilation fans in the economizer mood on a scheduled basis. Care should be taken to prevent excessive fan operation that would offset cooling energy savings. Also be sure that night humidity does not preclude the use of this strategy.

Exemptions:

- Projects in hot-dry and warm-humid climates

5.3.1.2 Individual ceiling mounted fan systems < 3,200 l/s (6,500 cfm)

Partial cooling

In addition to providing cooling with 100% outside air, economizers must also be capable of providing partial cooling. So when conditions require it, although additional mechanical cooling is needed, the economizer can assist in meeting the cooling load.

Testing

All air-side economizers shall be tested in the field to ensure proper operation following the requirements in ECBC Section 14: Appendix F: Air-Side Economizer Acceptance Procedures Envelope Summary. An exception is allowed if an air-side economizer is installed by a HVAC system equipment manufacturer and is certified to the building department as being factory-calibrated and tested per the procedures in ECBC Section 15: Appendix G: Compliance Forms.

Economizer Testing Procedure

Step 1: Simulation a cooling load and enable the economizer by adjusting the lockout control set point. Verify and document the following:

- Economizer damper modulates opens to 100% outside air.
- Return air damper modulates closed and is completely closed when economizer damper is 100% open.
- Economizer damper is 100% open before mechanical cooling is enabled
- Relief fan or return fan (if applicable) is opening or barometric relief dampers freely swing open

Step 2: Continue from Step 1 and disable the economizer by adjusting the lockout control set point. Verify and document the following:

- Economizer damper closes to minimum ventilation position
- Return air damper opens to at or near 100%
- Relief fan (if applicable) shuts off or barometric relief dampers closed. Return fan (if applicable) may still operate even when economizer is disabled.

5.3.2 Variable Flow Hydronic Systems

Fluid from the heating or cooling source is supplied to heat transfer devices, such as coils and heat exchangers, and back through the hydronic system. The ECBC requirements specify the type of equipment and capabilities in such a way to reduce pump energy. Variable fluid flow, automatic isolation valves, and variable speed drives enable the system to operate below design flow when possible.

Variable fluid flow

The ECBC requires that chilled or hot-water systems be designed for variable fluid flow and are capable of reducing pump flow rates to no more than the larger of 1) half of the design flow rate or 2) the minimum flow required by the equipment manufacturer for proper operation of the chillers or boilers.

Automatic isolation valves

Two-way Automatic Isolation Valves serve as a means of varying flow rate in a hydronic system. The valve is interlocked to shut off water flow when the compressor is off. Since this effectively creates a variable flow system, variable-speed drive controls are required.

The ECBC requires two-way automatic isolation valves for water-cooled air-conditioning or heat pump units with a circulation pump motor greater than or equal to 3.7 kW (5 hp). The valves must be on each water cooled air-conditioning or heat pump unit that is interlocked with the compressor so that the condenser water flow can be shut off when the compressor is not operating.

Example 7: Hot water system compliance

Q: A hot water system has two-way valves at most coils, but occasional three-way valves are provided at the end of the branches to ensure flow through them. Does this design comply with the ECBC requirement?

A: Yes, as long as the total flow through the three-way valves does not exceed 50% of design flow. Water piping is generally designed for water velocities that are high enough so that the time it takes for chilled or hot water to leave the plant and reach the control valve will be seconds or minutes, a small enough time that the system will not be "starved" and no discomfort will result. To minimize energy use in variable flow systems, limit the use of three-way valves to one or two to prevent pump dead heading.

Example taken from ASHRAE 90.1-2004 User Guide

Variable speed drives

Variable speed drives are required to control chilled water and condenser water systems that have pump motors greater than or equal to 3.7 kW (5 hp).

5.3.2.1 XXX

5.3.2.2 XXX

5.3.2.3 XXX

HVAC EQUIPMENT FOR ENERGY CONSERVATION

Heat Recovery Systems

A common energy conservation opportunity is that of to utilize the heat transfer between various components of the HVAC system. The following are the some of the available strategies and equipments:-

Boiler Economizers: These achieve heat transfer by passing the hot gases in a boiler's stack through a heat exchanger, thus preheating the incoming boiler water as a energy conservation strategy

Runaround Coils: These can be used for heat transfer between intake and exhaust air ducts. Heat transfer between incoming and exhaust air streams through heat pipes, heat transfer wheels and desiccant systems can play major roles in energy conservation.

Economizer Cycles: These use cool outdoor air when available to ease the burden on a refrigerant cycle as it cools the re-circulated indoor air. (See section 5.3.1)

Geo-Exchange Systems: These ground source heating and cooling (GSHC) technologies use the earth or available water bodies as a heat source or heat sink for buildings. Geo-exchange technology transfers heat between the steady temperature of the earth/water and a building to maintain the building space conditions. The stable underground or under water temperatures provides a source for heat in the winter and a means to reject excess heat in the summer. In a geo-exchange system, a fluid is circulated between the building and the ground loop piping. In the summer, the fluid picks up heat from the building and moves it to the water/earth. In the winter, the fluid picks up heat from the ground/water and moves it to the building.

Thermal energy storage

This refers to technologies that store energy in a thermal reservoir for later reuse. They can be employed to balance energy demand between day time and night time. The thermal reservoir may be maintained at a temperature above (hotter) or below (colder) than that of the ambient environment. The principal application today is the production of ice, chilled water, or eutectic solution at night, which is then used to cool environments during the day. Thermal energy storage technologies can store heat (even from solar collectors) in an insulated repository for later use in space heating, domestic or process hot water, or to generate electricity. Most practical active solar heating systems have storage for a few hours to a day's worth of heat collected.

Variable Refrigerant Flow (VRF) Systems

This technology is used to transfer heat from warmer parts of the building to cooler parts. The term variable refrigerant flow (VRF) refers to the ability of the system to control the refrigerant amount flowing to each of the evaporators. This enables the use of many evaporators of differing capacities and configurations, individualized comfort control, simultaneous heating and cooling in different zones, and heat recovery from one zone to another. The energy efficiency of VRF systems derives from several factors. VRF technologies provide very good part-load performance by limiting conditioning to only those rooms that are occupied, thereby, making it an effective energy conservation strategy. The duct losses are also essentially eliminated through this technology, which are often estimated to be between 10% - 20% of the total airflow in a ducted system.

Typical VRF Configuration in an Office Building

Sources:

Stein, B., Reynolds, J., Grondzik W., & Kwok, A. (2005). Mechanical and Electrical Equipment For Buildings, 10th Ed. John Wiley & Sons Inc.

Goetzler W (2007).Variable Refrigerant Flow Systems. ASHRAE Journal 49 (4)

ENERGY CONSERVATION FOR HVAC SYSTEMS

1. **Reduce HVAC system operation when building or space is unoccupied:**
   - Reduce HVAC operating hours to reduce electrical, heating and cooling requirements
   - Eliminate HVAC usage in vestibules and unoccupied spaces
   - Minimize direct cooling of unoccupied areas by turning off fan coil units and unit heaters and by closing the vent or supply air diffuser
   - Turn fans off
   - Close outdoor air dampers
   - Install system controls to reduce cooling/heating of unoccupied space.

2. **Reduce HVAC operating hours:**
   - Turn HVAC off earlier
   - Install HVAC night-setback controls
   - Shut HVAC off when not needed
   - Adjust thermostat settings for change in seasons
   - Adjust the housekeeping schedule to minimize HVAC use
   - Schedule off-hour meetings in a location that does not require HVAC in the entire facility
   - Install separate controls for zones
   - Install local heating/cooling equipment to serve seldom-used areas located far from the center of the HVAC system
   - Install controls to vary hot water temperature based on outside air
   - Use variable speed drives and direct digital controls on water circulation pumps motors and controls.

3. **Adjust areas that are too hot or too cold:**
   - Adjust air duct registers
   - Use operable windows for ventilation during mild weather
   - Use window coverings (blinds, awnings etc.) to cut down on heat loss and to avoid heat gain
   - Use light-colored roofing and exterior wall material with high reflectance to reflect heat
   - Incorporate outside trees to create shade
   - Install ceiling fans
   - Create zones with separate controls.

4. **Reduce unnecessary heating or cooling:**
   - Set the thermostat higher in the cooling season and lower in the heating season
   - Allow a fluctuation in temperature, usually in the range of 68° to 70°F for heating and 78° to 80° for cooling
   - Adjust heating and cooling controls when weather conditions permit or when facilities are unoccupied
   - Adjust air supply from the air-handling unit to match the required space conditioning
   - Eliminate reheating for humidity control (often air is cooled to dewpoint to remove moisture, then is reheated to desired temperature and humidity).

5. **Install an economizer cycle**
   Instead of operating on a fixed minimum airflow supply, an economizer allows the HVAC system to utilize outdoor air by varying the supply airflow according to outdoor air conditions, usually using an outdoor dry bulb temperature sensor or return air enthalpy (enthalpy switchover). Enthalpy switchover is more efficient because it is based on the true heat content of the air.

6. **Employ heat recovery**
   A heat exchanger transfers heat from one medium to another. Common types of heat exchangers are: rotary, sealed, plate, coil run-around system, and hot oil recovery system. Install heat recovery ventilators that exchange between 50 and 70 percent of the energy between the incoming fresh air and the outgoing return (conditioned) air.

7. **Minimize the amount of air delivered to conditioned space**
   The amount of air delivered to a space is dependent upon heating/cooling load, delivery temperature, ventilation requirements and/or air circulation or air changes. On average the air should change every five to 10 minutes. Reducing airflow will reduce horsepower. Extend the time frame for circulation of air by using a fan discharge damper, fan vortex damper (fan inlet), or fan speed change.

8. **Minimize exhaust and make-up air**
   Makeup air depends on the needs of ventilation for personnel, exhaust air from workspaces, overcoming infiltration, machine air needs, and federal, state and local requirements.
   - Seal ducts that run through unconditioned space (up to 20 percent of conditioned air can be lost in supply duct run)
   - Keep doors closed when air conditioning is running
   - Properly insulate walls and ceilings
   - Insulate air ducts, chilled water, hot water and steam pipes
   - Rewire fans to operate only when lights are switched on, as codes permit
   - Check for damper leakage/ensure tight seals
   - Shut off unneeded exhaust fans and reduce use where possible
   - Reduce air volume lost by reducing exhaust rates to the minimum
   - Review process temperatures
   - Install thermal windows to minimize cooling and heating loss.

9. **Implement a regular maintenance plan:**
   - Inspect to ensure dampers are sealed tightly
   - Clean coil surfaces
   - Ensure doors and windows have tight seals
   - Check fans for lint, dirt or other causes of reduced flow
   - Schedule HVAC tune-ups (the typical energy savings generated by tune-up is 10 percent)
   - Check and calibrate thermostat regularly
   - Replace air filters regularly
   - Inspect ductwork
   - Repair leaks
   - Turn off hot water pumps in mild weather.

Maintenance for an expert:
   - Reduce fan speeds and adjust belt drives
   - Check valves, dampers, linkages and motors
   - Check/maintain steam traps, vacuum systems and vents in one-pipe steam systems
   - Repair, calibrate or replace controls.

Cooling system maintenance:
   - Clean the surfaces on the coiling coils, heat exchangers, evaporators and condensing units regularly so that they are clear of obstructions
   - Adjust the temperature of the cold air supply from air conditioner or heat pump or the cold water supplied by the chiller (a 2° to 3°F adjustment can bring a three to five percent energy savings)
   - Test and repair leaks in equipment and refrigerant lines

- Upgrade inefficient chillers.

Fuel-fired heating system maintenance (possible five to 10 percent in fuel savings):

- Clean and adjust the boiler or furnace
- Check the combustion efficiency by measuring carbon dioxide and oxygen concentrations and the temperature of stack gases; make any necessary adjustments
- Remove accumulated soot from boiler tubes and heat transfer surfaces
- Install a fuel-efficient burner.

Control setting maintenance:

- Determine if the hot air or hot water supply can be lowered
- Check to see if the forced air fan or water circulation pump remains on for a suitable time period after the heating unit, air conditioner or chiller is turned off to distribute air remaining in the distribution ducts.

10. Implement an energy management system (EMS):

An EMS is a system designed to optimize and adjust HVAC operations based on environmental conditions, changing uses and timing. Create an energy management system to automatically monitor and control HVAC, lighting and other equipment.

11. Upgrade fuel-burning equipment:

- Install a more efficient burner
- Install an automatic flue damper to close the flue when not firing
- Install turbulators to improve heat transfer efficiency in older fire tube boilers
- Install an automatic combustion control system to monitor the combustion of exit gases and adjust the intake air for large boilers
- Insulate hot boiler surfaces
- Install electric ignitions instead of pilot lights.

12. Evaluate thermostat controls and location:

- Install programmable thermostats
- Lock thermostat to prevent tampering
- Ensure proper location of thermostat to provide balanced space conditioning
- Note the proximity of the heated or cooled air producing equipment to thermostat.

13. Evaluate boiler operations.

- Investigate preheating boiler feed water
- Adjust boilers and air conditioner controls so that boilers do not fire and compressors do not start at the same time but satisfy demand
- Use hot water from boiler condensate to preheat air.

14. Use existing cooling towers to provide chilled water instead of using mechanical refrigeration for part of the year.

15. Install water meters on cooling towers to record makeup water usage.

16. Install controls on heat pump (if has electric resistance heating elements) to minimize use. Install a variable air volume system (VAV) with variable speed drives on fan motors. A VAV system is designed to deliver only the volume of air needed for conditioning the actual load.

17. Upgrade to premium efficiency models when available

Source: North Carolina Department of Environment & Natural Resources (NCDENR). (2003). Energy Efficiency in Industrial HVAC Systems

6 SERVICE WATER HEATING AND PUMPING

6.1 GENERAL

Overview

Service water heating (SHW) plays a small part in the energy use of a commercial building. There are only several mandatory provisions that need to be checked to ensure that the water heating system meets the requirements of the ECBC.

6.2 MANDATORY REQUIREMENTS

The ECBC seeks to minimize Service Water Heating (SWH) energy usage by:

- Requiring partial SWH in some instances
- Regulating SWH equipment efficiency
- Maximizing heat recovery and minimizing electric supplemental heat sources
- Requiring pipe insulation
- Reducing standby losses with heat traps
- Requiring swimming pool covers
- Requiring compliance documentation.

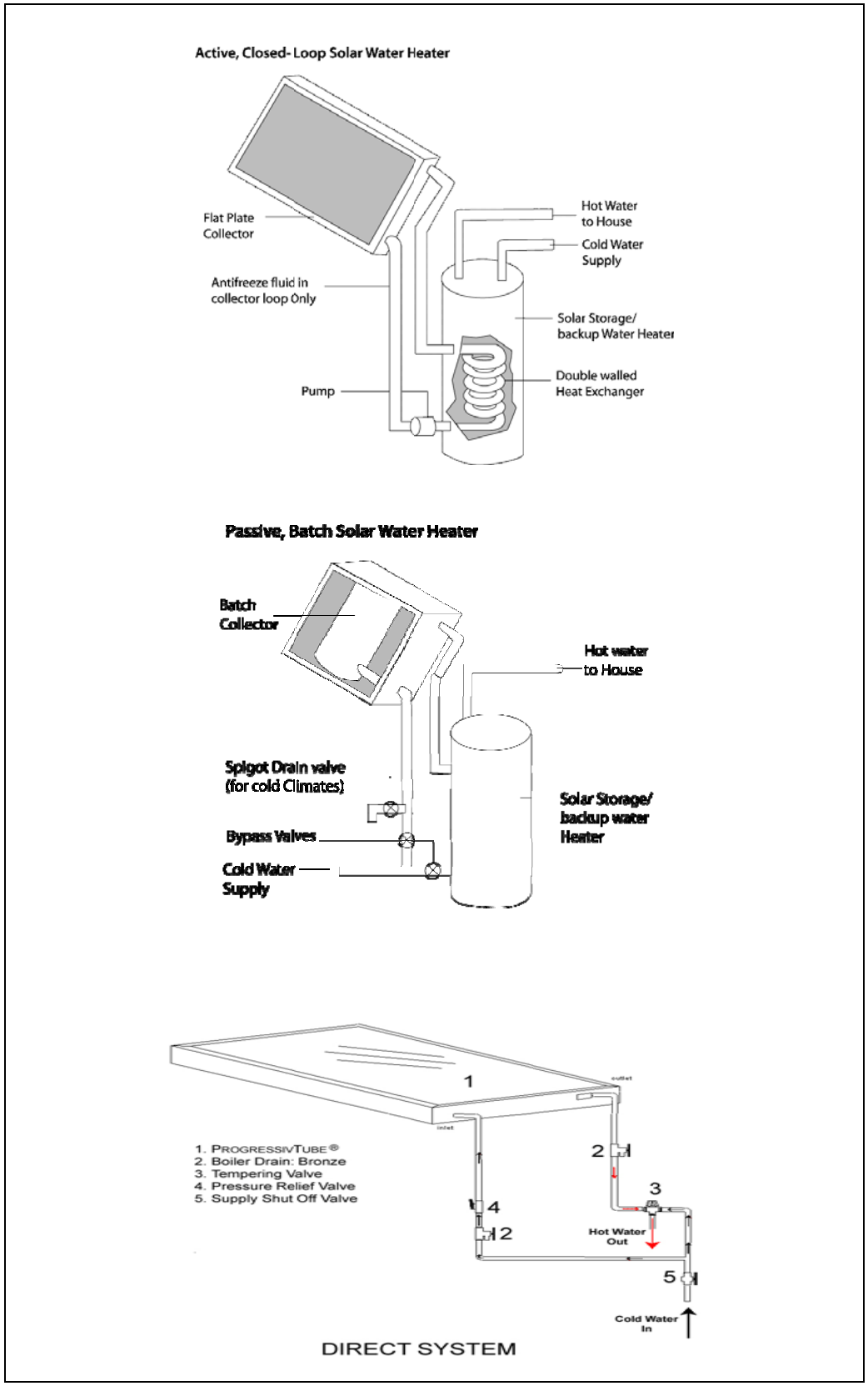
6.2.1 Solar Water Heating

The ECBC requires that residential facilities, hotels and hospitals with centralized systems have a solar water heating system for at least 1/5 of the design capacity. In other words, the provision of solar water heating system should be at least 20% of the total hot water requirement.

An exception is provided for systems that use heat recovery for at least 1/5 or 20% of the design capacity. Heat recovery water heating is the heating of domestic hot water with the waste heat from the air conditioning system. This heat is rejected from the air conditioner's condenser to the atmosphere. By recovering this wasted heat and utilizing it to heat water, it is possible to substantially reduce water-heating costs.

There are two types of solar water heaters. Passive heaters collect and store solar thermal energy for domestic water heating applications and do not require electrical energy in put for recirculating water through a solar collector. Active heaters collect and store solar thermal energy for domestic water heating applications and require electrical energy input for operation of pumps or other components. Figure 17 below shows examples of solar water heating systems.

Figure 17: Examples of Solar Water Heating Systems



6.2.2 Equipment Efficiency

The mandatory requirements for the ECBC include minimum efficiencies presented in available Indian Standards for the various water heating equipment such as electric and gas heaters, instantaneous heaters, boilers, and pool heaters. These efficiency requirements are presented in available Indian Standards as follows:

Table 25: Conditions for Thermal Performance Test of SDHW System (Clause 9.5.2)

Time (h)	Incident Radiation			Hour Angle, w (°)	Incident angle, θ (°)	Load (liters)
	Non-Solar Day kJ/ (m^2·h)	G_{bp} kJ/(m^2·h)				
0 800-0 900	0	694	576	-60	60	0.2V
0 900-1 000	0	1,224	576	-45	45	
1 000-1 100	0	1,624	576	-30	30	
1 100-1 200	0	1,884	576	-15	12	
1 200-1 300	0	1,964	576	0	0	0.2V
1 300-1 400	0	1,884	576	15	15	
1 400-1 500	0	1,624	576	30	30	
1 500-1 600	0	1,224	576	45	45	
1 600-1 700	0	694	576	60	60	
1 700-1 800						0.2V
1 800-1 900						0.2V
1 900-2 000						0.2V
Total	0	12,816	5,184			V

Source- IS 13129: Solar Heating- Domestic Water Heating Systems (Part 1 performance Rating procedure using Indoor Test Methods)

Table 25: Standardized Conditions for analysis of Long Term Energy Savings (Clause 6.7)

Months	Climate1		Climate 2		Fraction of normal load
	g (MJ/m^2·d)	T_e (°C)	g (MJ/m^2·d)	T_e (°C)	
Jan	24	22	22	20	0.7
Feb	23	22	20	20	0.8
Mar	21	21	18	18	0.85
Apr	18	18	14	15	0.9
May	16	15	11	12	0.95
Jun	14	12	9	10	1.0
Jul	16	11	10	9	1.0
Aug	18	12	13	11	1.0
Sep	20	14	16	12	1.0
Oct	22	17	18	15	0.95
Nov	23	19	19	16	0.9
Dec	24	21	20	18	0.8

Source: IS 13129 (Part 2): 1991Solar Heating- Domestic Water Heating Systems (Part 2 Procedure for system performance characterization and yearly performance prediction)

- Reference IS 15558: gas instantaneous water heaters must meet the performance/minimum efficiency level with above 80% efficiency.
- Reference IS 2082: electric water heaters much meet the described performance/minimum efficiency levels.

Energy Factor (EF) and thermal efficiency (Et) ratings which measure the overall efficiency of water heater systems are set as minimum requirements. The mandatory standby loss (SL) is set as a *maximum* Btu/h. Fifteen to thirty percent of the energy consumed by a standard water heater goes to keeping the water hot while it's not being used. This lost energy is called standby loss. Gas water heaters have higher standby losses than electric water heaters because of the uninsulated flue running up the center of the tank. Demand heaters (also called tankless or instantaneous heaters) reduce standby loss by heating water only as it flows through the heater on its way to a faucet actually in use. Instantaneous water heaters with input rates below 58.62 W must comply with these requirements if the water heater is designed to heat water to 82.2ºC or higher.

Advantages of heat pumps

Heat pump water heaters are more efficient since electricity is used to transfer heat in a vapor compression cycle. A heat pump water heater is an electric water heater that uses a compressor to transfer thermal energy from one temperature level to a higher temperature level. Energy Factors for heat pump water heaters are over 1.5.

Water Heating System Efficiency

Reduce standby losses from storage tank and pipes.

Lower Water Heating Temperature. Use a hot water system with a thermostat. Service water heating energy use and operating costs can be reduced by simply lowering the thermostat setting on your water heater. For each 5.5ºC (10ºF) reduction in water temperature, can save between 3%–5% in energy costs.

Insulate the storage tank. Install a water heater insulation blanket; the higher the R-value, the better. Use wire or twine or straps to insure that the blanket stays in place. Some new high efficiency heaters should not be insulated; consult the equipment manual provided by the manufacturer. Gas water heaters should not be insulated on top or within about 8" of the bottom of the water tank. Set an electric water heater on a rigid foam insulation board. This step is most critical when the heater sits on a concrete slab, but it's always a good idea. Install the water heater in a heated location. The colder the air surrounding the heater, the more the standby loss. Indoor gas heaters should be sealed combustion or fan-forced draft.

Insulate pipes and use heat traps. Insulate all exposed pipes. The R-value of pipe insulation is dependent on wall thickness; thicker is better. A 5/8" wall thickness should be considered minimum for foam insulation, while 3" is the minimum for fiberglass wrap. Heat trap nipples work best to eliminate convective losses from the tank into the plumbing, but pipe loops also work if the drop is at least 6".

What is a heat trap?

Heat traps are valves or loops of pipe that allow water to flow into the water heater tank but prevent unwanted hot-water flow out of the tank. The valves have balls inside that either float or sink into a seat, which stops convection. These specially designed valves come in pairs. The valves are designed differently for use in either the hot or cold water line. Heat traps can help save energy and cost on the water heating bill by preventing convective heat losses through the inlet and outlet pipes.

Types of Water Heaters

Storage Gas – A gas water heater designed to heat and store water at less than 180°F. Water temperature is controlled with a thermostat. Storage gas water heaters have a manufacturer's specified storage capacity of at least two gallons and less than 75,000 But/h input.

Large Storage Gas – A storage gas water heater with greater than 75,000 Btu/h input.

Storage Electric – An electric water heater designed to heat and store water at less than 180°F. Water temperature is controlled with a thermostat. Storage electric water heaters have a manufacturer's specified capacity of at least two gallons.

Storage Heat Pump – An electric water heater that uses a compressor to transfer thermal energy from one temperature level to a higher temperature level for the purpose of heating water. It includes all necessary auxiliary equipment such as fans, storage tanks, pumps or controls. EFs for heat pump water heaters are found in the Energy Commission's Appliance Database under Certified Water Heaters.

Instantaneous Gas - A gas water heater controlled manually or automatically by water flow activated control or a combination of water flow and thermostatic controls, with a manufacturer's specified storage capacity of less than two gallons.

Instantaneous Electric - An electric water heater controlled automatically by a thermostat, with a manufacturer's specified storage capacity of less than two gallons. Note: Instantaneous water heaters are not generally designed for use with solar water heating systems or as heat sources for indirect fired water heaters. They are also typically inappropriate for use with recirculation systems. Consult manufacturer's literature when considering these applications.

Indirect Gas - A water heater consisting of a storage tank with no heating elements or combustion devices, connected via piping and recirculating pump to a heat source consisting of a gas or oil fired boiler, or instantaneous gas water heater (see note following the definitions of Instantaneous Gas and Electric).

Passive Solar -Systems, which collect and store solar thermal energy for domestic water heating applications and do not require electricity to recirculate water through a solar collector.

Active Solar -Systems, which collect and store solar thermal energy for domestic water heating applications requiring electricity to operate pumps or other components.

Wood Stove Boilers - Wood stoves equipped with heat exchangers for heating hot water.

Temperature Controls

Water-heating systems are required to have controls that are adjustable down to a 49°C setpoint or lower. An exception is made where a higher setting is recommended by the manufacturer to prevent condensation and possible corrosion. To comply with this requirement, the water heater must have thermostatic control with an accessible setpoint. This setpoint must be adjustable down to whichever is lower: 49°C or the minimum manufacturer's recommended setting to prevent condensation. Both standby and distribution losses will be minimized by designing a system to provide hot water at the minimum temperature required. Table 27: Service Water Temperature summarizes the recommended hot water design temperatures In addition to the potential energy savings, maintaining water temperature as low as possible reduces corrosion and scaling of water heaters and components. Another important benefit is improved safety with respect to scalding. Accidental scalding from temperatures as low as 60°C is responsible for numerous deaths each year. The Standard requires automatic temperature controls for public lavatory faucets to limit the outlet temperature to 43°C. Designers should be aware that the bacteria that cause Legionnaire's disease has been found in service water heating systems and can colonize in hot water systems maintained below 46°C. Careful maintenance practices can reduce the risk of contamination. In health-care facilities or service-water systems maintained below

60°C, periodic flushing of the fixtures with high temperature water or other biological controls may be appropriate.

Table 27: Service Water Temperature

Use	Temperature °F
Lavatory	105
Hand Washing	115
Showers and tubs	110
Therapeutic baths	95
Commercial and institutional laundry	<180
Residential dishwashing and laundry	140
Surgical scrubbing	110
Rack Type	>150 wash
	180 to 195 final rinse
Single tank conveyor-type	>160 wash
	180 to 195 final rinse
Multiple tank conveyor-type	>150 wash
	>160 pumped rinse
	180 to 195 final rinse
Chemical sanitizing-type	140 wash
	>75 rinse

6.2.3 Supplementary Water Heating System

Supplemental Water Heating System shall be designed to maximize efficiency and shall incorporate and prioritize the following design features as shown:

1. Maximum heat recovery from hot discharge system like condensers of air conditioning units

2. Use of gas fired heaters wherever gas is available

3. Electric heater as last resort.

6.2.4 Piping Insulation

To minimize standby losses, the ECBC requires that pipelines for the entire hot water system, including the storage tanks, shall be insulated conforming to the relevant IS standards on materials and applications. Piping insulation must comply with ECBC Section 5.2.4.1.

FAQs 14: Demand Water Heaters

What is a demand water heater?

Demand (or "tankless" or "instantaneous") water heaters provide hot water only as it is needed. They don't produce the standby energy losses associated with storage water heaters, which can save you money.

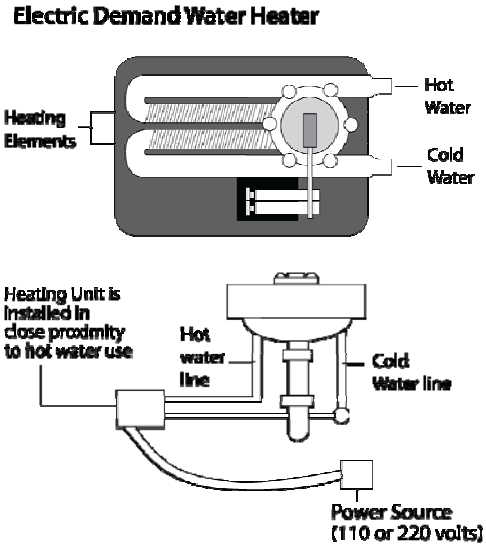
What are standby losses?

These losses account for energy lost while storing heated water. This includes any heat losses through the water heater tank wall, fittings, and flue, plus any pilot light energy. Standby loss depends on the design and insulation of the water heater, as well as the

difference between the temperature of the water and that of the air around the tank. Water heating energy can be reduced by decreasing standby losses.

How do demand water heaters work?

Demand water heaters heat water directly without the use of a storage tank. Therefore, they avoid the standby heat losses associated with storage water heaters. When a hot water tap is turned on, cold water travels through a pipe into the unit. Either a gas burner or an electric element heats the water. As a result, demand water heaters deliver a constant supply of hot water. You don't need to wait for a storage tank to fill up with enough hot water. However, a demand water heater's output limits the flow rate.


Electric Demand Water Heater
Heating Elements
Hot Water
Cold Water
Heating Unit is installed in close proximity to hot water use
Hot water line
Cold Water line
Power Source (110 or 220 volts)

Distribution systems for water heater

Standard - Standard system without any pumps for distributing hot water.

Point of Use - System with no more than 8 feet of horizontal distance between the water heater and hot water fixtures, except laundry.

Hot Water Recovery - System that reclaims hot water from the distribution piping by drawing it back to the water heater or other insulated storage tank.

Pipe Insulation - R-4 (or greater) insulation applied to 3/4 inch or larger, non-recirculating hot water mains in addition to insulation required by the Standards, Section 150(j) (first five feet from water heater on both hot and cold water pipes).

Parallel Piping - Individual pipes from the water heater to each point of use.

Continuous Recirculation - Distribution system using a pump to recirculate hot water to branch piping though a looped hot water main with no control of the pump, such that water flow is continuous. Pipe insulation is required.

Temperature Recirculation - Uses temperature controls to cycle pump operation to maintain recirculated water temperatures within certain limits. Pipe insulation is required.

Time Recirculation - Uses a timer control to cycle pump operation based on time of day. Pipe insulation is required.

Time/Temp Recirculation - Uses both temperature and timer controls to regulate pump

operation. Pipe insulation is required.

Demand Recirculation - Uses brief pump operation to recirculate hot water to fixtures just prior to hot water use when a demand for hot water is indicated.

Recirculation/Demand w/Hot Water Recovery - Combined system consisting of Recirculation: Demand and Hot Water Recovery.

Recirculation/Demand w/Pipe Insulation - Combined system consisting of Recirculation: Demand and Pipe Insulation.

6.2.5 Heat Traps

Heat traps stop hot water from rising into the distribution pipes and forming a natural circulation loop. Heat traps are required in the inlet and outlet piping of all vertical pipe risers serving storage water heaters and storage tanks serving a non-recirculating system. These should be located as close as practical to the storage tank. Heat traps may either be installed internally by the manufacturer, installed as an after-market add-on, or site-fabricated. Site fabricated heat traps may be constructed by creating a loop or inverted U-shaped arrangement to the inlet and outlet pipes (See Figure 18 and Figure 19).

Figure 18: Heat Trap

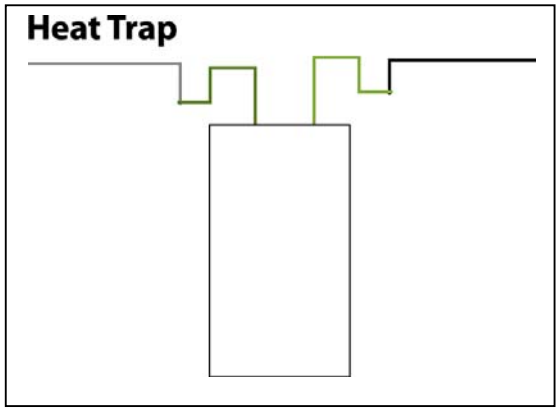
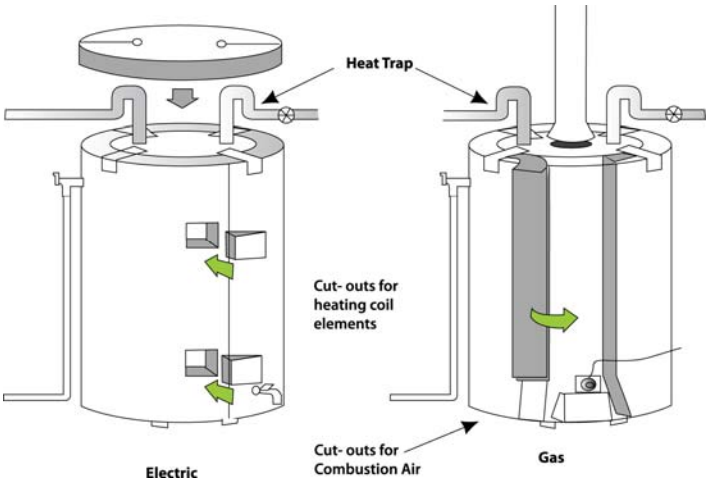


Figure 19: Heat Trap Elements



6.2.6 Swimming Pools

Swimming pools of both the residential and commercial variety are becoming commonplace in contemporary society. Observably, swimming pools can be a source of considerable water loss due to evaporation. Secondly, the cost of the energy required to maintain the temperature of the water in the pool at a level comfortable for swimming is a strong incentive to adopt measures which promote retention of heat in the pool and retain heat loss. Heated pools can be a source of significant heat and humidity gain in a building. The ECBC requires that all interior or exterior heated pools shall be provided with a vapor retardant pool cover on or at the water surface. Pools heated to more than 32°C (90°F) shall have a pool cover with a minimum insulation value of R-2.1 (R-12).

An exception is provided for pools deriving over 60% of their energy from site-recovered energy or solar energy source.

6.2.7 Compliance Documentation

When submitting building applications for approval, they must include detailed calculations that demonstrate 1) the SHW system is designed to ensure that at least 20% of the heating requirement is met from solar heat/heat recovery, 2) not more than 80% of the heat is met from electrical heating, and 3) where gas is available, not more than 20% of the heat shall be met from electrical heating.

7 LIGHTING

7.1 GENERAL

Overview

Electricity for lighting is the largest energy end-use in commercial buildings, typically accounting for 20-40 percent of the total energy consumption. Lighting is also a significant power demand on the electric grid and contributes significantly to the amount of energy needed for cooling. Efficient lighting systems can help to reduce total energy use and save money, protect precious natural resources, and help to reduce the overall amount of greenhouse gases produced by the commercial building sector.

An energy efficient lighting design involves sensitive integration of many strategies that include building orientation, interior building layout, daylight strategies, glazing specification, choice of lighting system and controls and etc. Many things can go wrong with the building lighting system and the well-intentioned attempts to make it energy efficient. Critical missteps to watch out for include:

- Specifying the amount of light for general usage without considering the needs of specific tasks (for example, supplying light for general office work but not addressing the effect of glare on computer screens)
- Designing a daylighting strategy but not enabling the lighting system to dim or turn off when there is sufficient daylight in the interior space
- Supplying inadequate control of lighting by not allowing lights to be adjusted to specific needs (i.e. turned on in groups or "banks", or dimmed), and not providing easily accessible control switches;
- Adding a large window area to the façade for daylighting but ignoring the problems of solar heat gain and the need for shading
- Designing/sizing the building's HVAC system on rules of thumb and not accounting for the reduction in cooling.

The ECBC limits energy consumption and electrical demand by requiring lighting controls, specifying exit signs and outdoor ground lighting, limiting the amount of power that can be used for lighting in buildings, and encouraging daylighting (see Envelope section).

The lighting requirements in the ECBC apply to:

- Interior spaces of buildings
- Exterior building features, including facades, illuminated roofs, rchitectural features, entrances, exits, loading docks, and illuminated canopies
- Exterior building grounds lighting that is provided through the buildings electrical service.

The following areas DO NOT need to comply:

- Emergency lighting that is automatically off during normal building operation and is powered by battery, generator, or other alternate power source
- Lighting in dwelling units.

General Design Considerations

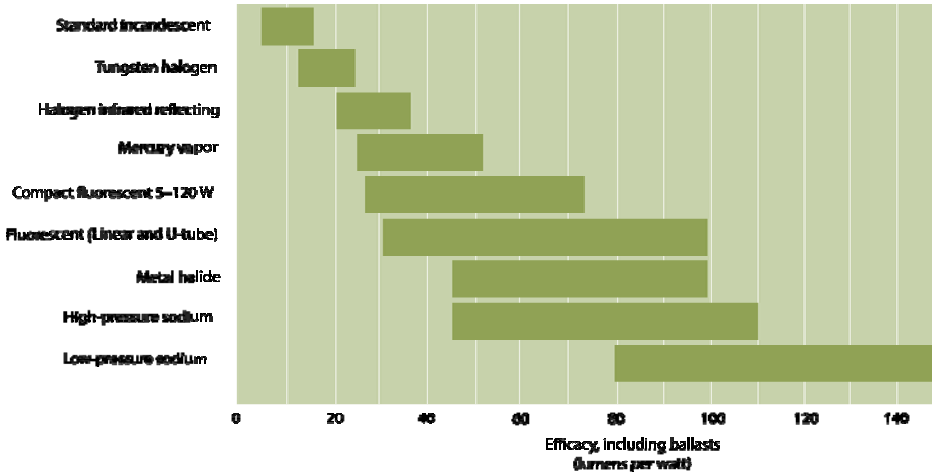
Using energy-efficient lighting equipment is a critical part of designing a lighting system that uses less energy while maintaining or even improving lighting conditions. Lighting is one of the fastest developing energy-efficient technologies. Energy-efficient alternatives available in the market include T8 and T5 linear fluorescent lamps, mercury vapor lamps, sodium lamps, Light Emitting Diodes (LED's) etc. For instance, modern fluorescent lighting, such as T-8's or T-5's, consume as little as two-thirds the energy of antiquated fluorescent lighting. Similarly, compact fluorescent sources are three to four times more efficient than the incandescent lamps they are designed to replace.

FAQs 15: Lighting

How is Lighting Efficiency (Efficacy) measured?

The most common of lighting efficiency or 'Efficacy' is the the lumens produced by a lamp/ballast system divided by the total watts of input power, expressed in lumens per watt. The resulting value is lumens per watt, sometimes referred to as LPW. Lamp efficacy values are based exclusively on the lamp's performance and do not include ballast losses. Lamp system efficacy values measures the performance of the lamp and ballast combination and this includes the ballast losses.

Relative efficacy of major light sources (Lumens/Watt)



What is a "luminaire"?

A "luminaire" is the lighting industry's term for light fixture. A luminaire consists of the housing, power supply (ballast), lamp, reflector, and, in some cases, a lens. A "lamp" is the lighting industry's term for a light bulb. Luminaires can be designed to be recessed into the ceiling, suspended by a rod or chain, or surface-mounted on the wall or ceiling.

How do you identify a high-efficacy luminaire?

A high-efficacy luminaire is one that contains only high-efficacy lamps and does not contain a conventional medium screw-based socket. Typically, high-efficacy luminaires contain pin-based sockets, like compact or linear fluorescent lamp sockets, though other types such as screw sockets specifically rated for high intensity discharge lamps (like metal halide lamps) may also be eligible for exterior use. Luminaires with modular components that allow conversion between screw-based and pin-based sockets without changing the luminaire

housing or wiring are not considered high efficacy luminaires.

These requirements prevent low-efficacy lamps from being used in high-efficacy luminaires. Also, in compact fluorescent luminaires with permanently installed ballasts that are capable of operating a range of lamp wattages, the highest operating input wattage of the rated lamp/ ballast combination must be use for determining the luminaire wattage.

There are two qualifying requirements for a high-efficacy luminaire: 1) the lumens per watt for the lamp must be above a specified threshold, and 2) electronic ballasts must be used in certain applications.

What are the requirements for recessed fixtures?

Luminaires that are recessed into insulated ceilings should be rated for insulation contact ("IC-rated") so that insulation can be placed over them. The housing of the luminaire should be airtight to prevent conditioned air from escaping into the ceiling cavity or attic, and unconditioned air infiltrating from the ceiling into the conditioned space.

Lighting for security purposes is a big concern; how is it regulated?

Lighting that is specifically designated as required by a health or life safety statue, ordinance or regulation is exempt from the exterior lighting power requirement. For required internal space controls, the required control device may be remotely installed if required for reasons of safety or security.

7.2 MANDATORY REQUIREMENTS

Mandatory requirements refer to requirements that must be met regardless of compliance approach or building type. The mandatory requirements for lighting mostly relate to lighting controls, and include:

- Automatic lighting shutoff
- Space controls
- Controls for daylighted areas
- Exterior lighting controls
- Additional independent controls.

There are also mandatory requirements for exit sign wattage and exterior building grounds lighting sources.

7.2.1 Lighting Control

Lighting controls are essential to an energy efficient commercial building. They allow lighting to be turned down or completely off when it is not needed – the simplest way to save energy. Maximizing the use of controls involves developing a set of strategies that utilize the ECBC requirements for various devices, including on-off controls, dimming controls, and systems that combine the use of both types of equipment. These controls can be quite sophisticated, but in general, they perform two basic functions: 1) they turn lights off when not needed, and 2) they modulate light output so that no more light than necessary is produced. The equipment required to achieve these functions varies in complexity from simple timers to intricate electronic dimming circuits, each applicable to different situations. Controls include time clocks, occupant and motion sensors, automatic or manual daylighting controls, and astronomical time switches (automatic switches that adjust for the length of the day as it varies over the year).

Lighting Control

It is worthwhile to determine the amount of local vs. central control that is needed from the lighting control system. Manual lighting controls range from a single switch to a bank of switches and dimmers that are actuated by toggles, rotary knobs, push buttons, remote control, and other means. Manual controls can be cost-effective options for small-scale situations. However, as the lighting system grows, automated systems become more cost-effective and are better at controlling light. Manual controls often waste energy because the decision to shut off the lights when they are not needed is based entirely on human initiative.

The following issues should be kept in mind while designing controls:

- Install a separate control circuit for each lighting element that operates on a distinct schedule
- Where light fixtures are needed in a predictable variety of patterns, install programmable switches
- Install lighting controls at visible, accessible locations
- Where lighting is needed on a repetitive schedule, use time clock control
- Install occupancy sensors in bathrooms, conference rooms and other spaces not in constant use.

7.2.1.1 Automatic Lighting Shutoff

Although there is no simpler way to reduce the amount of energy consumed by lighting systems than to manually turn lights off whenever not needed, this is not done as often as it could be. In response to that problem, the ECBC requires several automatic switches that either mark time or sense the presence of occupants. A sample diagram for an automatic lighting control system is shown below in Figure 20.

All interior lighting systems in buildings larger than 500 m2 (5,000 ft^2) are required to be equipped with automatic control devices. Within these buildings, occupancy sensors must be installed in the following spaces:

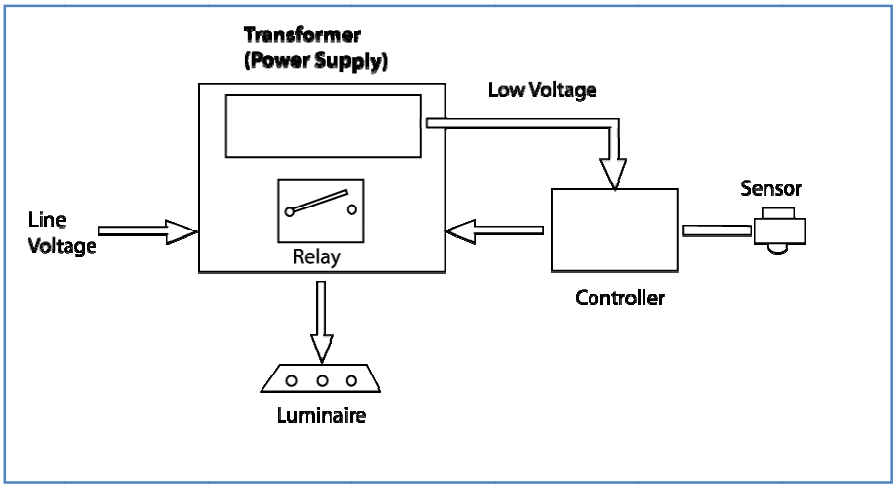
- All office areas less than 30 m2 (300 ft2) enclosed by walls or ceiling-height partitions,
- All meeting and conference rooms,
- All school classrooms, and
- All storage spaces.

For other types of interior spaces, an automatic control device is required to function on either:

- A scheduled basis at specific programmed times. For this option, an independent program schedule must be provided for all areas of no more than 2,500 m2 (25,000 ft^2) and not more than one floor; or
- Occupancy sensors that turn lighting off within 30 minutes of an occupant leaving the space. If controlling light fixtures controlled with occupancy sensors, the fixtures must also have a wall mounted, manual switch capable of turning off the lights when the space is occupied.

Any buildings designed for 24-hour use are exempt from automatic control requirements.

Figure 20: Automatic Lighting Control



7.2.1.2 Space Control

Along with controls for individual lights or sets of fixtures, master controls are required for each space which can shut off all the lights within the space. For example, the last person leaving the office is much more likely to use a master switch than to go through the office turning off every switch. Similarly, a cleaning crew can easily use master switches to turn lights off at the end of a shift.

Each space enclosed by ceiling-height partitions is required to have at least one control device to independently control the lighting within the space. The device can be a switch that is activated either manually or through an automatic occupant sensor. Each control device, regardless of type, must have the following functions:

a. Control a maximum of 250 m2 (2,500 ft2) for a space less than or equal to 1,000 m2 (10,000 ft2), and a maximum of 1,000 m2 (10,000 ft2) for a space greater than 1,000 m2 (10,000 ft2) (See Figure 21).

b. Be capable of overriding the required shutoff control [ECBC 7.2.1] for no more than 2 hours, and

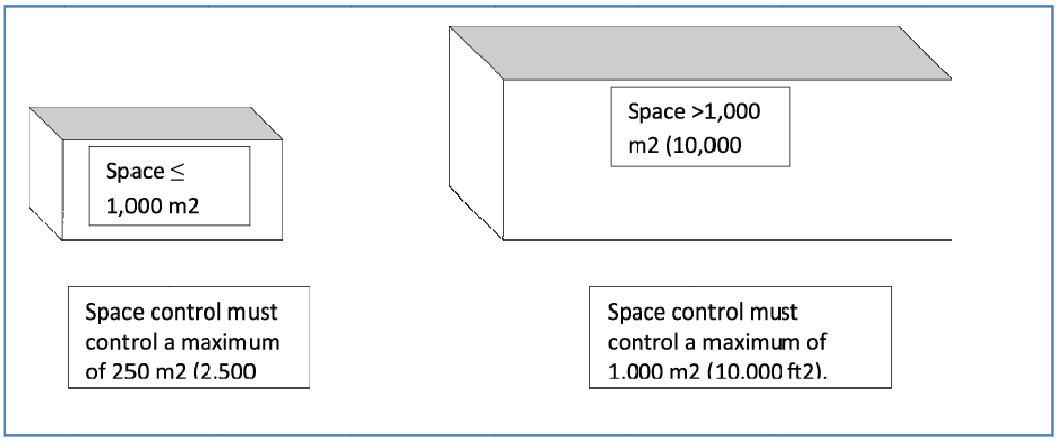
c. Be readily accessible and located so the occupant can see the control.

An exception to (c) is provided for control devices that need to be remotely installed for reasons of safety or security. However, a remotely located device must have a pilot light indicator as part of or next to the control device and it must be clearly labeled to identify the controlled lighting device.

7.2.1.3 Control in Daylighted Areas

ECBC requires controls (photo sensors etc.) that can reduce the light output of luminaires in any day lit space, by at least half. All luminaires in daylighted areas greater than 25 m2 (250 ft2) must have a manual or automatic control device that is capable of reducing the light output of the luminaires in the daylighted areas by at least 50%, and controlling only the luminaires located entirely within the daylighted area.

Figure 21: Requirements for Space Controls



Daylighted Areas

In general, *Daylighted Area* refers to the daylight illuminated floor area under horizontal fenestration (skylight) or adjacent to vertical fenestration (window). For horizontal fenestration, the daylighted area is specifically the area under a skylight, monitor, or sawtooth configuration with an effective aperture greater than 0.001 (0.1%).

For both vertical and horizontal fenestration, the daylighted area is calculated as the horizontal dimension in each direction equal to the top aperture dimension in that direction plus either:

- The floor-to-ceiling height (H) for skylights, or
- 1.5 H for monitors, or
- H or 2H for the sawtooth configuration, or
- The distance to the nearest 1000 mm (42 in), or
- Higher opaque partition, or
- One-half the distance to an adjacent skylight or vertical glazing, whichever is least, as shown in the plan and section figures.

7.2.1.4 Exterior Lighting Control

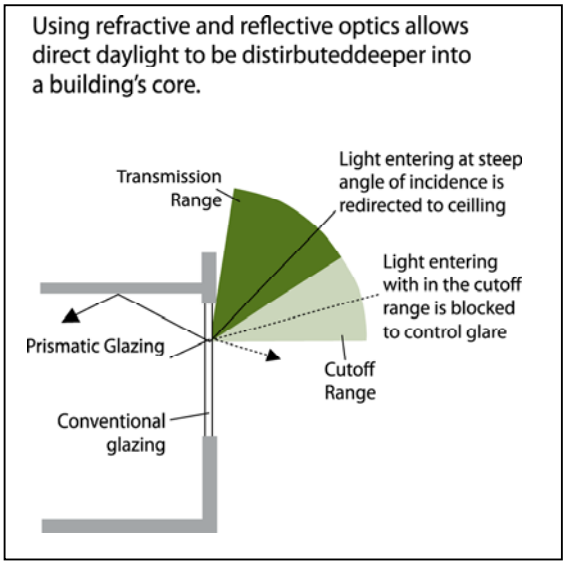
All non-exempt exterior lighting (see ECBC Section 7.3.5) where lighting is required must have one of the following:

- Automatic switching or photocell controls provided for all exterior lighting not intended for 24 hour operation
- Astronomical time switches that turn off when daylight is available.

Redirecting Daylight

Several technologies are available or under development for redirecting daylight so that it can be more effectively used in the interior of a building. Such systems use reflection, refraction, diffraction, or non-imaging optics to alter the distribution of incoming daylight These same principles are also used in light transport systems that carry and distribute daylight deep into a building's core.

How Light-bending panels can improve daylighting


Using refractive and reflective optics allows direct daylight to be distirbuteddeeper into a building's core.
Transmission Range
Light entering at steep angle of incidence is redirected to ceilling
Light entering with in the cutoff range is blocked to control glare
Prismatic Glazing
Cutoff Range
Conventional glazing

Sunlight redirecting systems work predominantly with direct, as opposed to diffuse, sunlight, and they are most effective on south facing walls. Options include various types of light shelves, laser-cut panels, prismatic acrylic panels, holographic optical elements, and sun-directing glass. All of these measures distort or impair the view, so they are typically placed above standing height.

The typical light shelf uses a reflective upper surface to direct sunlight from the window wall deeply into the interior of a room. Various means are available to increase the effectiveness of light shelves, including prismatic aluminized films, compound geometries designed to match particular solar altitudes, and movable systems that can be tuned to match the season or change the depth of sunlight penetration. Another variation on the theme is the between the- panes light shelf that uses the same principles of reflection but protects the elements between two panes of glass and can be manufactured in high volumes.

7.2.1.5 Additional Control

The following specialty lighting spaces are required to have a control device that separates lighting control from that of the general lighting:

- Display/accent lighting greater than 300m2 (3,000 ft2),
- Case lighting in display cases greater than 300m2,
- Hotel and motel guest rooms and guest suites (these shall have a master control device at the main room entry),
- Task lighting,
- Non-visual lighting, such as plant growth, and
- Demonstration lighting equipment (controls accessible only to authorized personnel).

FAQs 16: Lighting Controls

Q: An open office area is 900 m2. How many controls are required for this space?

A: Four, since this space is smaller than 1,000 m² each space control can serve a maximum area of 250 m².

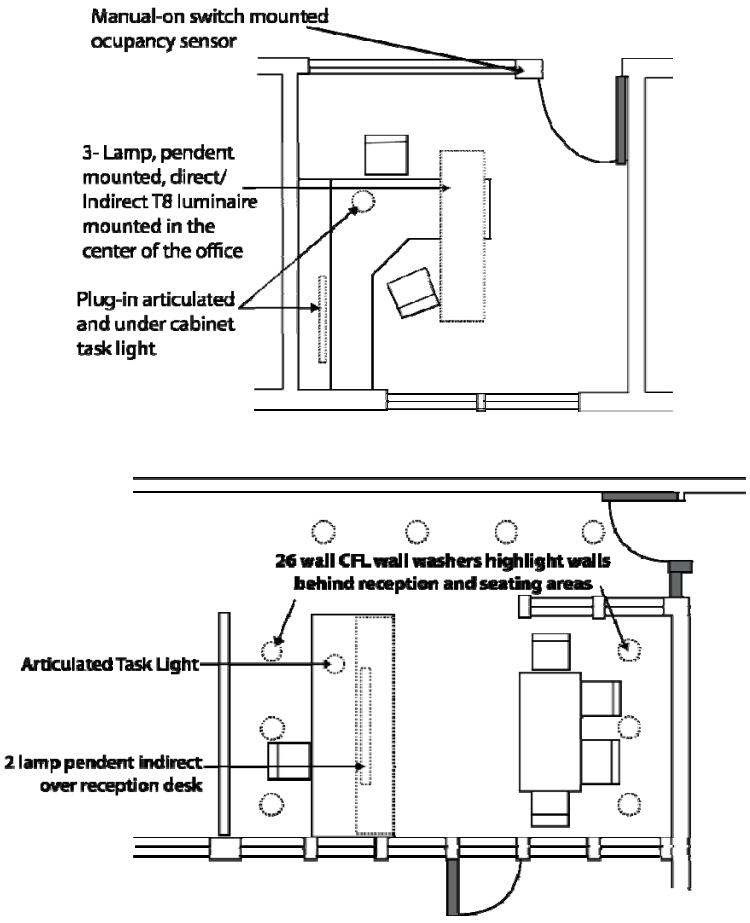
Q: In an open office 1,500 m2 how many controls are required?

A: Two, since this space is larger than 1,000 m2 each control can serve a maximum area of 1,000 m².

Q: A medical laboratory is studying the effect of lighting on a chemical process. Ordinary fluorescent luminaires are arranged over the test branch and connected to timers. This lighting is separate and distinct from the general lighting used throughout the laboratory. Is either the general lighting or the test lighting exempt?

A: The general lighting is covered by the Code. The test lighting is exempt. However, the test lighting should have separate controls.

Table 262: Lighting Diagrams


Manual-on switch mounted ocupancy sensor
3- Lamp, pendent mounted, direct/ Indirect T8 luminaire mounted in the center of the office
Plug-in articulated and under cabinet task light
26 wall CFL wall washers highlight walls behind reception and seating areas
Articulated Task Light
2 lamp pendent indirect over reception desk

7.2.2 Exit Signs

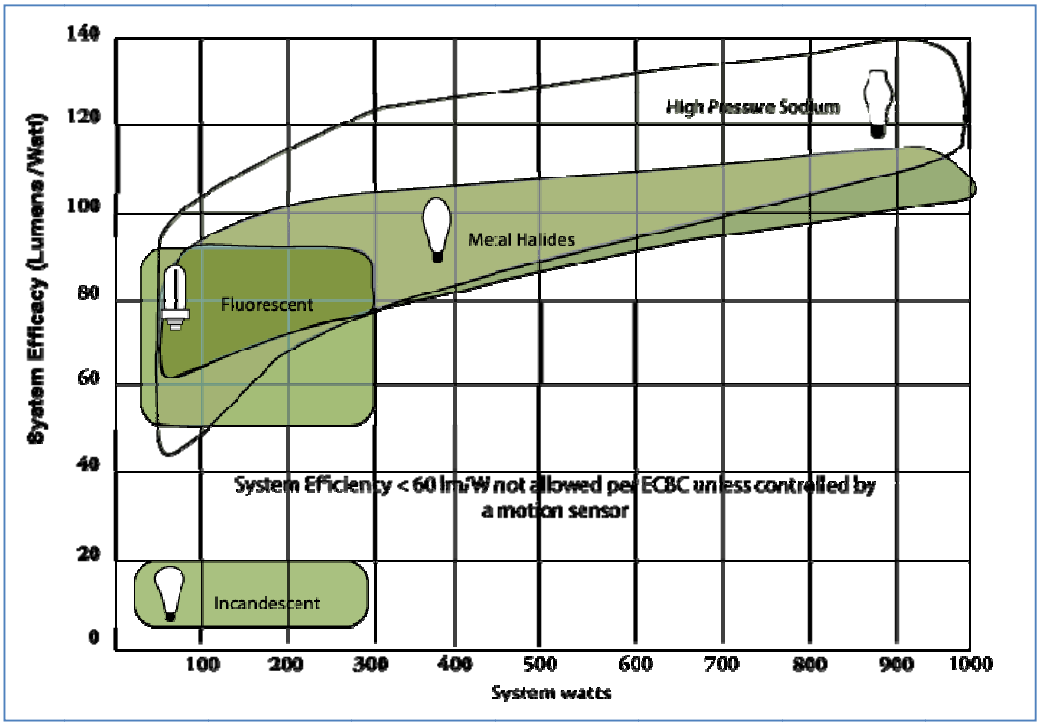
Electrically powered exit signs use either incandescent bulbs, compact fluorescent lamps (CFL) or light-emitting diode (LED) arrays as light sources. The ECBC mandates the maximum lighting power requirements for exit signs and requires that all internally-illuminated exit signs

not exceed 5 W per face. Most LED and some CFL exit signs meet this recommendation. Due to their low power draw, LED exit signs can be purchased with built-in back-up power supplies (i.e., batteries). With an estimated service life of 10 years or more, LEDs require significantly fewer lamp replacements than exit signs equipped with either incandescent lamps or CFLs.

7.2.3 Exterior Building Grounds Lighting

If luminaires used to light exterior building grounds operate with greater than 100W, they are required to have a minimum efficacy of ≥ 60 Lumens/Watt. An exception is allowed for luminaires that are either controlled with a motion sensor or are used for emergency lighting. As shown below in Figure 23, luminaires meeting these requirements include fluorescent, mercury vapor and high pressure sodium.

Figure 23: Watts per Lighting System Efficiency



7.3 PRESCRIPTIVE REQUIREMENTS

The prescriptive section of the lighting system requirements regulates both interior and exterior lighting power. The first may be determined by either of two different methods: the building area method or the space function method. One method must be selected and trading between methods are not accepted. Specific power limits are listed for exterior spaces.

7.3.1 Interior Lighting Power

Interior lighting includes all permanently installed general and task lighting shown on the plans. Interior lighting, for a building or a separately metered or permitted portion of a building, shall not exceed allowed power limits.

For Interior Lighting Power requirements, the installed interior lighting power is first calculated to include all lamps, ballasts, current regulators, and controls. A Lighting Summary Sheet is included in ECBC (See Figure 204). Compliance can then be achieved by following the Building Area Method or the Space Function Method. Both methods compare installed lighting power (as proposed) with maximum allowed lighting power densities (W/m^2) presented in tables based on either building area type or space function. When following either the Building Area or Space

Function method, the installed interior lighting power must be determined through calculation described in ECBC Section 7.3.4. The building area method is the simplest method to follow since fewer calculations are required. However, if the project applies to only a portion of the entire building, is not listed as a building type, or has more than one occupancy type, the space function method should be used to determine compliance.

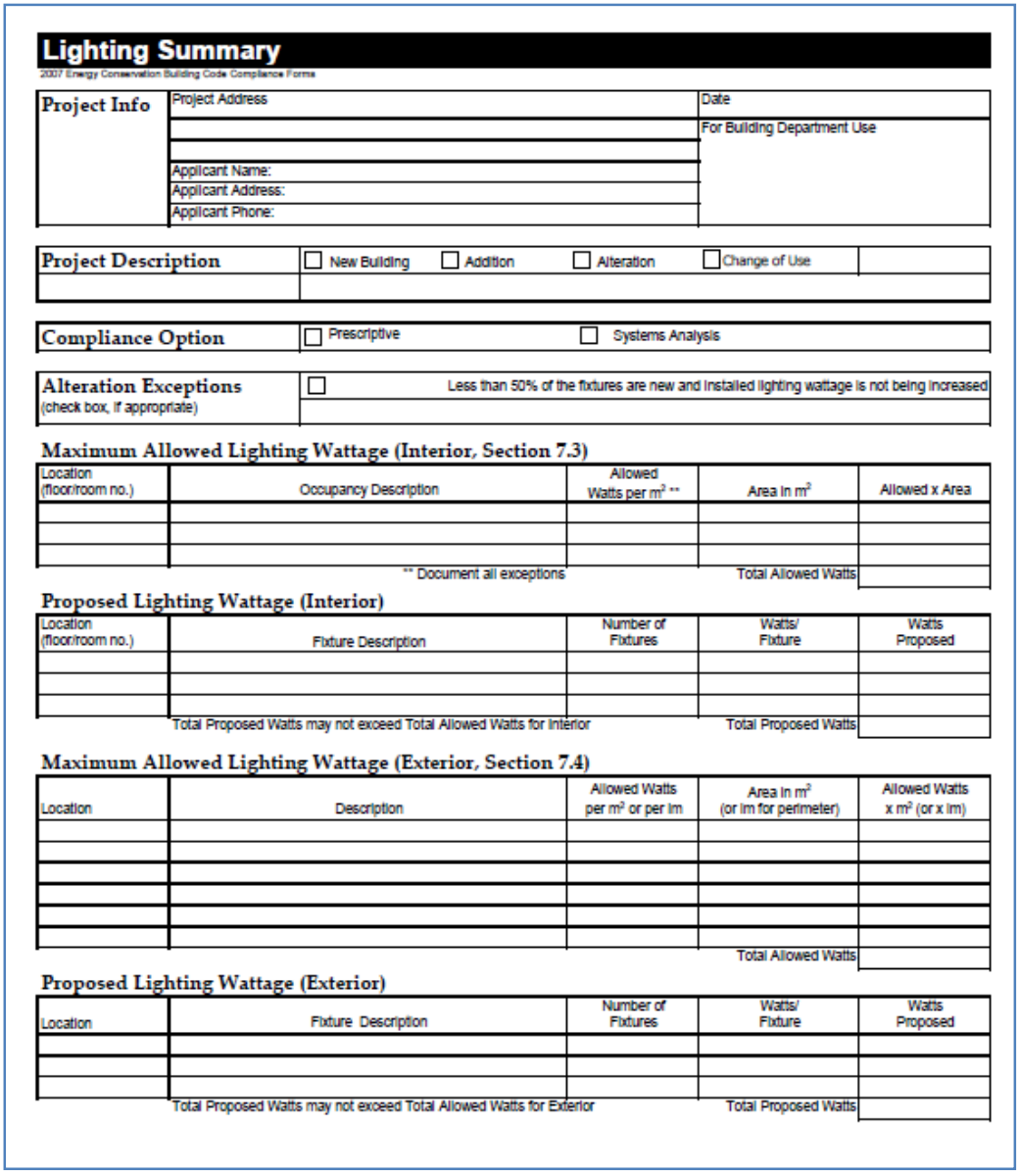
Trading of lighting power allowances are not permitted between portions of a building where different methods were used.

There are many exceptions to the lighting power requirement, generally for specialized lighting. These are listed in ECBC Section 7.3.1.

Lighting Power Exemptions

- Display or accent lighting that is an essential element for the function performed in galleries, museums, and monuments.
- Lighting that integral to equipment or instrumentation and is installed by its manufacturer.
- Lighting specifically designed for medical or dental procedures and lighting integral to medical equipment.
- Lighting integral to food warming and food preparation equipment.
- Lighting for plant growth or maintenance.
- Lighting spaces specifically designed for use by the visually impaired.
- Lighting in retail display windows, provided the displays are enclosed by ceiling height partitions.
- Lighting in interior spaces that have been specifically designated as a registered interior historic landmark.
- Lighting that is an integral part of advertising or directional signage
- Exit signs
- Lighting that is for sale or lighting educational demonstration systems.
- Lighting for theatrical purposes, including performance, stage, and film or video production.
- Athletic playing areas with permanent facilities for television broadcasting.

Figure 204: Lighting Summary Worksheet from ECBC Appendix G



Lighting Summary

2007 Energy Conservation Building Code Compliance Forms

Project Info	Project Address	Date
		For Building Department Use
	Applicant Name:	
	Applicant Address:	
	Applicant Phone:	

Project Description	☐ New Building	☐ Addition	☐ Alteration	☐ Change of Use	

Compliance Option	☐ Prescriptive	☐ Systems Analysis

Alteration Exceptions (check box, if appropriate)	☐ Less than 50% of the fixtures are new and installed lighting wattage is not being increased

Maximum Allowed Lighting Wattage (Interior, Section 7.3)

Location (floor/room no.)	Occupancy Description	Allowed Watts per m^2 **	Area in m^2	Allowed x Area
	** Document all exceptions		Total Allowed Watts	

Proposed Lighting Wattage (Interior)

Location (floor/room no.)	Fixture Description	Number of Fixtures	Watts/ Fixture	Watts Proposed
	Total Proposed Watts may not exceed Total Allowed Watts for Interior		Total Proposed Watts	

Maximum Allowed Lighting Wattage (Exterior, Section 7.4)

Location	Description	Allowed Watts per m^2 or per lm	Area in m^2 (or lm for perimeter)	Allowed Watts x m^2 (or x lm)
			Total Allowed Watts	

Proposed Lighting Wattage (Exterior)

Location	Fixture Description	Number of Fixtures	Watts/ Fixture	Watts Proposed
	Total Proposed Watts may not exceed Total Allowed Watts for Exterior		Total Proposed Watts	

7.3.2 Building Area Method

This method provides total watts per square meter for the entire building based on its type. The sum of all the interior lighting power cannot exceed the total watts to be in compliance. The first step is to determine the allowed power lighting densityfor appropriate building area categories listed in ECBC's *Table 7.1 Interior Lighting Power Building Area Method*. If more than one listed type applies to the area, the more general building area type should be used.

The second step is to calculate the gross lighted floor area for each of the building area types (this can be done using the building plans). Finally, the last step is to multiply the allowed watts per square meter listed for each selected building type by the corresponding lighted floor areas to determine the allowed watts (see Table 27).

Table 27: (ECBC Table 7.1) Interior Lighting Power- Building Area Method

Building Area Type	LPD (W/m^2)	Building Area Type	LPD (W/m^2)
Automotive Facility	9.7	Multifamily Residential	7.5
Convention Center	12.9	Museum	11.8
Dining: Bar Lounge/Leisure	14.0	Office	10.8
Dining: Cafeteria/Fast Food	15.1	Parking Garage	3.2
Dining: Family	17.2	Performing Arts Theater	17.2
Dormitory/Hostel	10.8	Police/Fire Station	10.8
Gymnasium	11.8	Post Office/Town Hall	11.8
Healthcare-Clinic	10.8	Religious Building	14.0
Hospital/Health Care	12.9	Retail/Mall	16.1
Hotel	10.8	School/University	12.9
Library	14.0	Sports Arena	11.8
Manufacturing Facility	14.0	Transportation	10.8
Motel	10.8	Warehouse	8.6
Motion Picture Theater	12.9	Workshop	15.1

In cases where both a general building area type and a specific building area type are listed, the specific building area type shall apply.

Example 8: Allowed Lighting Power Calculation – Building Area

Building type: New general office space occupying an entire building, totaling 10,000 m^2.

Allowable lighting power: 1.7 watts per m^2

The total allowed watts for the building is determined by multiplying Column B by Column D (17,000 watts).

A	B	C	D	E
Building or Area Type	Entire Building	Tenant Area or Portion of Building	Building or Space	Allowed Watts**
	(watts per m^2)	(watts per m^2)	(m^2)	(B or C x D)
Office	1.7	1.8	10,000	17,000
Total Allowed Watts				17,000

***Note that in the above example, only Column B or Column C can be used to determine the allowed lighting power qualify project. Do not use more than one column.*

7.3.3 Space Function Method

Similar to the building area method, the first step of the space function method is to determine the appropriate building type and their allowed lighting power densities, which varies according to the function of the space. These are listed in ECBC Table 7.2*, Interior Lighting Power – Space Function Method* (See **Error! Reference source not found.**9). Table 29

Table 28: (ECBC Table 7.2) Interior Lighting Power- Space Function Method

Space Function	LPD (W/m^2)	Space Function	LPD (W/m^2)
Office-enclosed	11.8	For Reading Area	12.9
Office-open plan	11.8	Hospital	
Conference/Meeting/Multipurpose	14.0	For Emergency	29.1
Classroom/Lecture/Training	15.1	For Recovery	8.6
Lobby*	14.0	For Nurse Station	10.8
For Hotel	11.8	For Exam Treatment	16.1
For Performing Arts Theater	35.5	For Pharmacy	12.9
For Motion Picture Theater	11.8	For Patient Room	7.5
Audience/Seating Area*	9.7	For Operating Room	23.7
For Gymnasium	4.3	For Nursery	6.5
For Convention Center	7.5	For Medical Supply	15.1
For Religious Buildings	18.3	For Physical Therapy	9.7
For Sports Arena	4.3	For Radiology	4.3
For Performing Arts Theater	28.0	For Laundry – Washing	6.5
For Motion Picture Theater	12.9	Automotive – Service Repair	7.5
For Transportation	5.4	Manufacturing Facility	
Atrium-first three floors	6.5	For Low Bay (<8m ceiling)	12.9
Atrium-each additional floor	2.2	For High Bay (>8m ceiling)	18.3
Lounge/Recreation*	12.9	For Detailed Manufacturing	22.6
For Hospital	8.6	For Equipment Room	12.9
Dining Area*	9.7	For Control Room	5.4
For Hotel	14.0	Hotel/Motel Guest Rooms	11.8
For Motel	12.9	Dormitory – Living Quarters	11.8
For Bar Lounge/Leisure Dining	15.1	Museum	
For Family Dining	22.6	For General Exhibition	10.8
Food Preparation	12.9	For Restoration	18.3
Laboratory	15.1	Bank Office – Banking Activity Area	16.1
Restrooms	9.7	Retail	
Dressing/Locker/Fitting Room	6.5	For Sales Area	18.3
Corridor/Transition*	5.4	For Mall Concourse	18.3
For Hospital	10.8	Sports Arena	
For Manufacturing Facility	5.4	For Ring Sports Area	29.1
Stairs-active	6.5	For Court Sports Area	24.8
Active Storage*	8.6	For Indoor Field Area	15.1
For Hospital	9.7	Warehouse	
Inactive Storage*	3.2	For Fine Material Storage	15.1
For Museum	8.6	For Medium/Bulky Material Storage	9.7
Electrical/Mechanical Facility	16.1	Parking Garage – Garage Area	2.2
Workshop	20.5	Transportation	
Convention Center – Exhibit Space	14.0	For Airport – Concourse	6.5
Library		For Air/Train/Bus – Baggage Area	10.8
For Card File & Cataloging	11.8	For Ticket Counter Terminal	16.1
For Stacks	18.3		

Second, for each space that is enclosed by partitions which are 80% or greater than ceiling height, the gross interior floor area must be determined. This applies to all space area types except for

retail. The gross interior floor area should be calculated by measuring to the center of the partition walls and must also include spaces allotted to balconies or other projections.

Finally, the individual lighting power allowances for each space is determined by multiplying its gross lighted floor area by the allowed lighting power density for that space. The lighting power allowances are summed to equal the *Interior Lighting Power Allowance* for the building.

Example 9: Allowed Lighting Power Calculation – Space Function

Building type: New general office space; occupying tenant area totally 10,000 m².

Allowable lighting power: A combination of general office and corridor, restroom, and support areas. The total allowed watts for the building is determined by multiplying the watts per m² for each area in Column C by the square meter of each area in Column D, below.

The total allowed watts value is determined by adding the values in Column E (17,000 watts).

A	B	C	D	E
Building or Area Type	Entire Building	Tenant Area or Portion of Building	Building or Space	Allowed Watts**
	(watts per m2)	(watts per m2)	(m2)	(B or C x D)
Corridor, Restroom, Support Areas	N/A	0.8	1,000	800
Office	1.7	1.8	10,000	16,200
Total Allowed Watts				17,000

***Note that in the above example, only Column B or Column C can be used to determine the allowed lighting power qualify project. Do not use more than one column.*

7.3.4 Installed Interior Lighting Power

To determine the installed interior lighting power, the calculation must include all power used by the luminaires, including lamps, ballasts, current regulators, and control devices except as specifically exempted in the ECBC. However, if two or more independently operating lighting systems in a space are controlled to prevent simultaneous user operation, the installed interior lighting power calculation must be based solely on the lighting system with the highest power.

7.3.4.1 Luminaire Wattage

The ECBC requires that luminaire wattage be incorporated into the installed interior lighting power calculation as follows:

- For incandescent luminaires with medium base sockets which do not contain permanently installed ballasts, the wattage used must be the maximum labeled wattage of the luminaires.
- For luminaires containing permanently installed ballasts, the wattage used must be the operating input wattage of the specified lamp/ballast combination. This is based on values from manufacturers' catalogs or values from independent testing laboratory reports.
- For all other miscellaneous luminaire types, the wattage used must be the specified wattage of the luminaires.
- For lighting tracks, plug-in bus ways, and flexible-lighting systems that allow the addition and/or relocation of luminaires without altering the wiring of the system, the wattage used must be the larger of either the specified wattage of the luminaires included in the system or 135 W/m (45 W/ft). Systems with integral overload protection, such as fuses

or circuit breakers, shall be rated at 100% of the maximum rated load of the limiting device.

7.3.5 Exterior Lighting Power

Lighting power limits are specified for building exterior lighting applications in ECBC Table 7.3 (See Table 30). The connected lighting power for these applications must not exceed these allowed limits. In addition, trade-offs between applications are not permitted.

Exemptions are allowed for the following lighting applications ONLY if they are equipped by an independent control device:

- Specialized signal, directional, and marker lighting associated with transportation.
- Lighting used to highlight features of public monuments and registered historic landmark structures or buildings.
- Lighting that is integral to advertising signage.
- Lighting that is specifically designated as required by a health or life safety statute, ordinance, or regulation.

Any exterior lighting applications not listed in able 7.3, and not exempt (as described above), are required to simply comply with the mandatory requirements in *Section 7.2.3 Exterior Building Grounds Lighting*. This requires luminaires operating at greater than 100W to contain lamps with minimum efficacy of 60 lm/W, unless the luminaire is controlled by a motion sensor.

Table 30: (ECBC Table 7.3) Interior Lighting Building Power

Exterior Lighting Applications	Power Limits
Building entrance (with canopy)	13 W/m^2 (1.3 W/ft^2) of canopied area
Building entrance (without canopy)	90 W/lin m (30 W/lin f) of door width
Building exit	60 W/lin m (20 W/lin f) of door width
Building facades	2 W/m^2 (0.2 W/ft^2) of vertical facade area

8 ELECTRICAL POWER

8.1 GENERAL

Overview

There are no prescriptive requirements for the electrical power system. Instead, the ECBC has only mandatory requirements for energy efficient design of electrical installations in buildings. Generally, these fall into the following four categories:

- Minimizing losses in the power distribution system.
- Reduction of losses and energy wastage in the utilization of electrical power.
- Reduction of losses due to the associated power quality problems.
- Appropriate metering.

General Design Considerations

Significant energy savings are sought by maximizing the performance to the electrical distribution systems in buildings—from power factor losses to thermal monitoring of junction boxes and main power distribution boards.

8.2 MANDATORY REQUIREMENTS

The mandatory requirements of the ECBC cover the following elements of a building's electrical system:

- Transformers
- Motors
- Power factor correction
- Check–metering and monitoring
- Power distribution.

8.2.1 Transformers

Transformers are used within commercial buildings to supply electrical power to individual circuits for lighting, plug loads, air conditioning, and other applications. Transformers reduce the higher voltages used by electric utilities for power distribution to lower levels required by building equipment. They are generally located out of sight in mechanical spaces and other out-of-the-way locations and are, therefore, forgotten about when considering energy efficiency. Transformers last a long time (on the order of 35 years), thus opportunities for energy-saving upgrades are best captured for newly installed transformers or when replacement is due.

Electrical power distribution transformers are used in virtually every commercial building. They are energized around the clock, providing power to the building's electrical equipment and consuming energy whether or not this equipment is operating. Because distribution transformers consume energy even when the building is not occupied or equipment is not operating, more efficient distribution transformers result in savings around the clock, every day of the year.

8.2.1.1 Maximum Allowable Power Transformer Losses

The ECBC lists ratings for various transform sizes of dry type and oil filled transformers and their associated losses at 50% and full loading (Table 31Table and

Table 32). The proper rating and design selected must satisfy the minimum acceptable efficiency.

Table 31: (ECBC Table 8.1) Dry-Type Transformers

Rating KVA	Max. Losses at 50% loading kW*	Max. Losses at 100% loading kW*	Total losses at 50% loading kW*	Total losses at rated load kW*
	Up to 22 kV class		33 kV class	
100	0.94	2.4	1.12	2.4
160	1.29	3.3	1.42	3.3
200	1.5	3.8	1.75	4
250	1.7	4.32	1.97	4.6
315	2	5.04	2.4	5.4
400	2.38	6.04	2.9	6.8
500	2.8	7.25	3.3	7.8
630	3.34	8.82	3.95	9.2
800	3.88	10.24	4.65	11.4
1000	4.5	12	5.3	12.8
1250	5.19	13.87	6.25	14.5
1600	6.32	16.8	7.5	18
2000	7.5	20	8.88	21.4
2500	9.25	24.75	10.75	26.5

Table 32: (ECBC Table 8.2) Oil Filled Transformers

Rating KVA	Max. Losses at 50% loading kW*	Max. Losses at 100% loading kW*	Total losses at 50% loading kW*	Total losses at rated load kW*
	Up to 11 kV class		33 kV class	
100	520	1800	560	1820
160	770	2200	780	2580
200	890	2700	900	3000
250	1050	3320	--	--
315	1100	3630	1300	4300
400	1450	4630	1520	5100
500	1600	5500	1950	6450
630	2000	6640	2300	7600
1000	3000	9800	3450	11350
1250	3600	12000	4000	13250
1600	4500	15000	4850	16000
2000	5400	18400	5700	18500
2500	6500	22500	7050	23000

In the building industry, it is very common that transformers are part of a turn-key project. The contractor is often interested in a transformer with a low purchase price. However, the user/owner of the transformer wants the cheapest transformer, i.e. with the lowest total owning cost, which complies with the requirements for a given application. Losses, installation, maintenance, repair and decommissioning costs are seldom taken into account by the contractor when choosing between transformers. The ECBC requires only that the *Total Lost Energy Cost* be considered when transformers are selected. When comparing transformers with respect to energy losses, the process is called loss *evaluation*.

The concept of evaluation can be applied to transformers with the assumptions that the annual losses and the load level remain steady at an equivalent annual value, the tariff is constant and the rates of inflation and interest are constant. These assumptions have obvious limitations, but the Total Lost Energy concept is a widely used method for evaluation.

The total losses for dry type transformers should conform to the draft standard of Indian Standard IS 2026: Part 11, 2007 (shown in Table 8.1). Total losses for oil filled transformers should conform to Table 8.2 (as specified in Central Electricity Authority norms).

Transformers selection must account for minimal total initial cost in addition to the present value of the operational costs of estimated loads for it life span.

Calculating Present Value

The cost of a transformer includes the initial investment and ongoing payment of energy charges during a given period. The Total Lost Energy Cost can be calculated by adding the present worth of future energy charges. This accounts for future energy expenses and shows a better measure of comparing equipment with higher first cost, but a higher efficiency, and thus lower running charges.

Present value is also known as *Present Worth*. The deferred monetary gains/expenses are expressed in terms of their present worth (PW).

Example: If Rs 90.91 is invested at an annual interest of 10%, it will yield 90.91x (1+ 10/100) = Rs 100/- at the end of one year. Therefore, the present worth of Rs 100 after one year is Rs 90.91/- , if the annual rate of interest is 10%.

$PW = [(1 - [1+a/1+i]^n)/(i-a)]$

Where PW is Present Worth
a = per unit inflation index, annual
i = per unit interest rate
n = number of years

8.2.1.2 Measurement and Reporting of Transformer Losses

To measure losses, calculations must use calibrated digital meters of class 0.5 or better accuracy and be certified by the manufacturer. All transformers of capacity of 500 kVA and above must be equipped with additional metering class current transformers (CTs) and potential transformers (PTs) in addition to any utility requirements so that periodic loss monitoring studies may be carried out.

8.2.2 Energy-Efficient Motors

Electric motors are simply devices that convert electrical energy into mechanical energy. Like all electro-mechanical equipment, motors consume some "extra" energy in order to make the conversion. Efficiency reflects how much total energy a motor uses in relation to the rated power delivered to the shaft.

A motor's nameplate rating is based on output horsepower, which is fixed for continuous operation at full load. The amount of input power needed to produce rated horse power will vary from motor to motor, with more-efficient motors requiring less input wattage than less-efficient models to produce the same output. Electrical energy input is measured in watts, while output is given in horsepower. Output power for motors manufactured in other countries may be stated in watts or kilowatts. One horsepower is equivalent to 746 watts. The ECBC requires that permanently wired motors >0.375 kW expected to operate more than 1,500 and motors>50 kW expected to operate more than 500 hours per year, must have a minimum acceptable nominal full-load motor efficiency not less than IS 12615 for efficient motors.

The ECBC also requires that motor horsepower ratings do not exceed 200% of the calculated maximum load being served and that motor nameplates list the nominal full-load motor efficiencies and the full-load power factor.

Motor users should insist on proper rewinding practices for any rewound motor. If proper rewinding practices cannot be assured, the damaged motor should be replaced with a new, efficient motor. The EBCB requires that certificates be obtained for rewound motors indicating motor efficiency. After rewinding, a new efficiency test shall be performed and a record maintained.

Table 33: Energy Efficiency Measures for Motors and Benefits

Motors	
Measure	**Benefits**
Replace standard Efficiency motors with premium efficiency motors.	Better efficiency and power factor over load range. Cooler operation. Potentially longer life. Corrects for previous damage from rewinds and aging. Higher tolerance to voltage unbalance and fluctuations, overload, harmonics, heat.
Correct motors over sizing to better match motor to load.	Improved power factor. Potential for improved efficiency Reduced Energy use in cube law roads. Capital cost savings.
If rewinding use high quality practice, core loss testing.	Minimize core damage and efficiency loss. Cooler operation.
Good motor system maintenance: Monitor vibrant and noise, cleaning, measure and mitigate resistive hot spots, resistive and inductive imbalances and excess capacitance.	Longer motor life. Higher efficiency.
Consider advantage motor types (Switched reluctance permanent magnet).	Improved starting torque. Often smaller size. Improved variable speed control. High efficiency over wide range of speed and load.

FAQs 17: Motor

What is an energy-efficient motor?

Motor efficiency is the ratio of mechanical power output to the electrical power input, usually expressed as a percentage. Energy-efficient motors use less energy. Because they are manufactured with higher quality materials and techniques, they usually have higher service factors and bearing lives, less waste heat output, and less vibration, all of which increase reliability. This is often reflected by longer manufacturer's warranties.

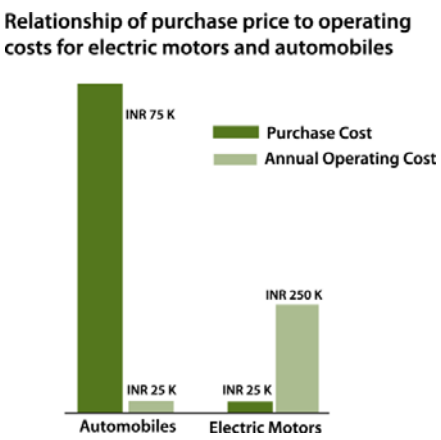
A 30 hp motor is in of replacement or rewinding. What would be the best course of action?

In general, it is best to replace a motor if it is less than 40 hp, the cost of the rewind exceeds 65 percent of the price of a new motor, or the motor was rewound prior to 1980.

A motor runs at 215% of the calculated maximum load being served. Does this comply with ECBC requirements?

No, the code requires motors not exceed 200% of the maximum calculated load. Since motors run most efficiently near their designed power rating, it is good practice to operate between 75 percent and 100 percent of full load rating.

Relationship of purchase price to operating costs for electric motors and automobiles



Many energy-using devices cost much more to buy than the energy they use in a year. A typical American car under normal use, for example, costs about 30 times as much to buy as it costs in gasoline each year to run . But electric motors are a notable exception. A motor running at a typical commercial or industrial sector duty factor of 4,000 hours per year or more will consume on the order of ten times its capital cost's worth of electricity every year, and roughly two hundred times its cost over a 20-year service life.

Example 10: Calculating savings from use of an energy-efficient motor

This simple calculation will determine the kW saved with an energy efficient motor using two similar motors operating at the same load:
kW saved = hp x L x 0.746 x [(100/Estd) – (100/Ehe)]
kWh savings = kW saved x Annual Operating Hours

Total Savings = (kW saved x 12 x monthly demand charge) + (kWh savings x energy charge)

The above equations apply to motors operating at a specified constant load. For varying loads, you can apply the energy savings equation to each portion of the cycle where the load is relatively constant for an appreciable period of time. The total energy savings is then the sum of the savings for each load period. Determine the demand savings at the peak load point. The equations are not applicable to motors operating with pulsating loads or for loads that cycle at rapidly repeating intervals.

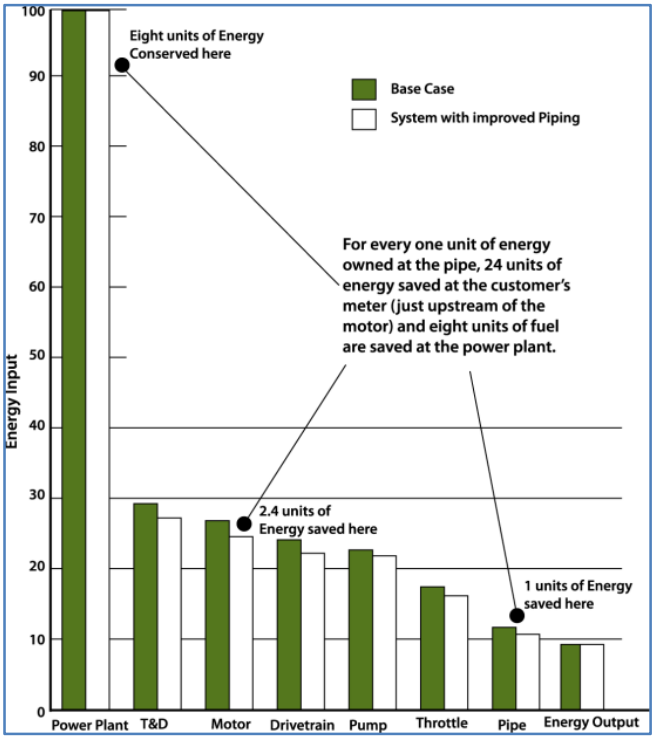
Kilowatts Saved:

kW saved = *hp x Load x 0.746 x* (100/Estd – 100/Ehe)
= 75 *x* .75 *x* 0.746 *x* (100/91.6 – 100/94.1)
= 1.21

Energy Saved:

kWh savings = Hours of operation x kW saved
= 8,000 *hours x* 1.21
= 9,680 *kWh/year*

Figure 25: Energy lost at each step in base case



Energy lost at each step in base case

The graph (Figure 25) shows the percent of energy lost at each step in the base case system, which requires 100 units of fuel input at the power plant to deliver 9.5 units of energy output in the form of fluid flow exiting the pipe. The bar chart compares the base case to an otherwise identical system that has a one-unit reduction in pipe friction—by making the pipe slightly larger, smoother, straighter, or by using better valves. This one-unit savings at the downstream end of the system is compounded by efficiencies of the upstream components to yield 2.4 units of savings at the utility meter just upstream of the motor and over eight units of fuel savings at the power plant.

8.2.3 Power Factor Correction

Power factor correction is the process of adjusting the characteristics of electric loads in order to improve power factor so that it is closer to unity (i.e. 1). In simplified, electrical terminology, power factor is the difference between real (kW) and reactive power (kvar). It is a measure of how effectively current is being converted into useful work output and, more specifically, is a good indicator of the effect of the load current on the efficiency of the supply system. Power factor correction (PFC) may be applied either by an electrical power transmission utility to improve the stability and efficiency of the transmission network or, correction may be installed by individual electrical customers to, for example, reduce costs charged to them by their electricity supplier while simultaneously improving energy efficiency. A high power factor is generally desirable in a transmission system to reduce transmission losses and improve voltage regulation at the load. PFC is normally achieved by the addition of capacitors to the electrical network which reduce the burden on the supply.

All current will cause losses in the supply and distribution system. A load with a power factor of 1.0 results in the most efficient loading of the supply and a load with a power factor of 0.5 will result in much higher losses in the supply system. The ECBC requires that all electrical supplies

FAQs 18: Power

What are some of the benefits of Power Factor Correction?

- Reduced power consumption
- Reduced electricity bills
- Improved electrical energy efficiency
- Extra kVA availability from the existing supply
- Reduced I2R losses from transformer and distribution equipment
- Minimized voltage drop in long cables.

What are some ways to correct the power factor?

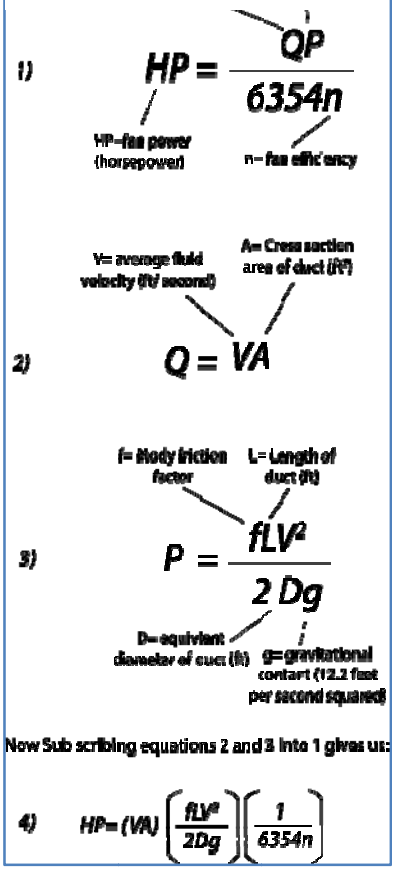
- Minimize operation of idling or lightly loaded motors
- Avoid operation of equipment above its rated voltage
- Replace standard motors as they burn out with energy-efficient motors. Even with energy-efficient motors, however, the power factor is significantly affected by variations in load. A motor must be operated near its rated capacity to realize the benefits of a high power factor design.
- Install capacitors in your AC circuit to decrease the magnitude of reactive power.

exceeding 100 A, 3 phases shall maintain their power factor between 0.95 lag and unity at the point of connection [ECBC 8.2.3].

Cube Law

The cube law can be demonstrated with the following equations (Figure 26) that apply to fluid flow. Our example is for a fan, but the equations apply to any fluid moved by turbo machinery against purely frictional resistance. Thus, fan power is proportional to fluid velocity cubed, subject to the limitations noted below. Fluid velocity is proportional to motor speed over a wide range.

Figure 26: Cube Law Equation

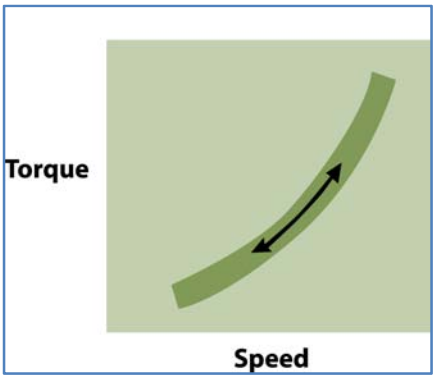

1)
HP = QP / 6354n
HP=fan power (horsepower)
n= fan efficiency
V= average fluid velocity (ft/ second)
A= Cross section area of duct (ft²)
2)
Q = VA
f= Body friction factor
L= Length of duct (ft)
3)
P = fLV² / 2 Dg
D= equivlent diameter of duct (ft)
g=gravitational contant (12.2 feet per second squared)
Now Sub scribing equations 2 and 3 into 1 gives us:
4)
HP= (VA) (fLV²/2Dg) (1/6354n)

Cube-law loads

The cube law applies to applications in which fans and centrifugal pumps are used to move air, water, and other fluids. It derives its name from the fact that the power such loads require increases with the cube of their speed For example, doubling the speed of a cube-law load increases power demand by eightfold Conversely, reducing its speed by 20 percent results in a roughly 50 percent drop in power requirements. The range of cube-law applications is vast, representing more than half of motor energy use. The cube law works both ways—small changes in speed can result in large increases or decreases in input power. This fact should be considered when switching from standard motors to energy efficient motors, because energy efficient motors can have lower slip. For example, a standard efficiency motor with 5 percent slip on a given load rotates at 1710 rpm, while an energy efficient motor might run the same load at 1750 rpm with 3 percent slip. This will increase the output of the driven device, but increase input

power much more because of the cube law. In this case (See Figure 27):

- The rotational speed of the motor and fan or pump increases by 2.3 percent (40 rpm/1710 rpm)
- Flow rate increases by 2.3 percent (by fan/pump laws)
- Average fluid speed increases by 2.3 percent, and Power required by the fan or pump increases by 7.1 percent (1.023 cubed).



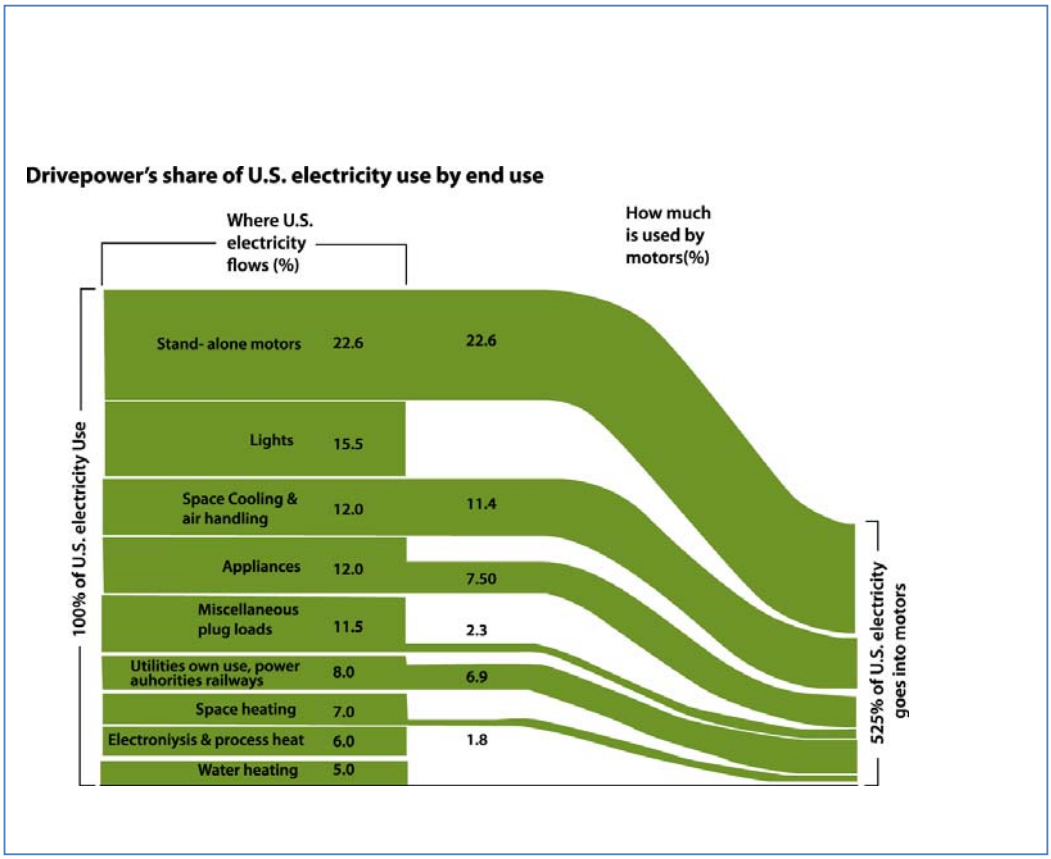
Improved *motor* efficiency will offset some of this increase, but if speed is not corrected to be the same with the energy efficient motor as with the standard motor, the efficiency gained may be more than offset by the load's higher power consumption.

Cube Law

The motor shaft is connected to—the load—is crucial in determining cube-law applicability. In general, the cube law applies only to loads in which required torque increases with speed because of fluid friction.

Consider a fan moving air through a simple duct loop. The fan is essentially doing no physical work other than overcoming the friction of the duct loop, so the power to drive the fan is the product of fan efficiency times flow times pressure (times a constant, to make units consistent). Assuming that fan efficiency is nearly the same at all speeds, fan power is proportional to flow times pressure. It turns out that both of these variables depend on the speed of the fan. Flow is proportional to speed (double the speed, double the flow). Pressure, however, is proportional to speed squared (double the speed, quadruple the pressure) because it is controlled by friction, which increases as air moves faster.

If we combine these relationships, we see that fan power is proportional to speed times speed squared, or speed cubed. It is the fact that fluid friction climbs steeply with speed that limits the maximum speed of a bicyclist on a flat road with no wind (air is a fluid). This relationship generally applies to all types of fluid friction in ducts and piping systems.



8.2.4 Check-Metering and Monitoring

A significant barrier to achieving energy efficiency during the operation of a building is inadequate metering systems and monitoring plans. Building operators cannot be expected to manage energy if they cannot measure energy use. To improve a building's energy performance over its operating life, and optimize the energy efficient requirements in the code, the ECBC requires that the building's performance be measured.

Metering is about having information that allows businesses to analyze and track changes in energy demand and, therefore, to manage their energy consumption more effectively. Energy metering is not a new concept and has been used by large energy-intensive businesses for many years to monitor and reduce waste. The ECBC requires that buildings have energy consumption metered to allow buildings to be easily monitored.

The ECBC requires check-metering based on three scenarios:

- Services >1,000 kVA must have permanently installed electrical metering to record:
    - Demand (kW)
    - Energy (kWh)
    - Total Power Factor (kVARh)
    - Current, Voltage, and total harmonic distortion (THD)\

2. Services<1,000kVA but >65 kVA must have permanent metering to record:
    - Demand (KW
    - Energy (kWh)
    - Total Power Factor (kVARh)

3. Services <65 kVA must have permanent electrical metering to record energy (kWh).

The widespread over sizing of induction motors

Motor over sizing is a subtle problem in industrial and commercial systems because, unlike most other application problems, it rarely manifests itself in the failure of a motor and the process shutdowns that follow. Rather, this problem is more like a low-level infection that saps energy and efficiency while padding utility bills for year after year. It takes concerted effort to evaluate motor loading, particularly in facilities where motors are widely distributed. In facilities where maintenance staff keep busy fixing breakdowns, assessment of motor loading may never occur.

Although motor over sizing can be an expensive problem in the long run, there are significant institutional and cultural reasons why motors are frequently and persistently oversized:

- When process systems are designed, their *maximum* torque requirements are noted for future motor selection. Unfortunately, this maximum torque value is usually translated into the *minimum* acceptable continuous torque for the motor even if the maximum process torque is required for only a small fraction of the motor's duty.

- If any of the design parameters of a system are poorly defined, or expected to change, motors are often oversized in an attempt to compensate for this uncertainty.

- Many systems are designed and constructed with future expansion in mind. Despite these good intentions, many of these expansions never occur, or occur in a dramatically different way than originally imagined. So even if the motors and loads were sized appropriately for application in the expanded system, they may run under loaded for years prior to its completion.

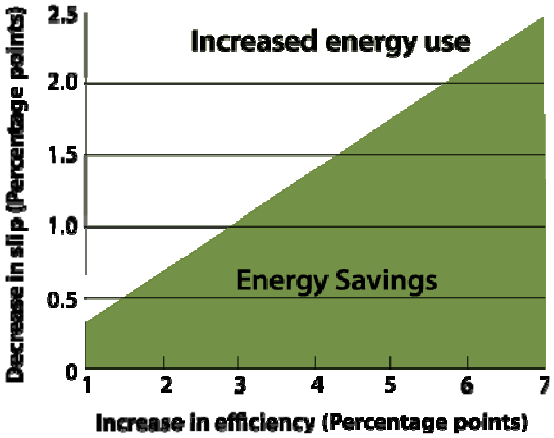
- In short, the methods by which motors are often selected can be characterized as an attempt to avoid the conspicuous failure of a grossly undersized motor by accepting the certain failure of an inefficiently applied and grossly oversized motor. Paradoxically, the cost of replacing a few inadvertently undersized motors with slightly larger models pales in comparison to the enormous added cost of operating all the "safely oversized" motors currently in use. Optimally sizing each motor for its application is the sound and most economically profitable policy.

Consequences of motor over sizing

When motors are oversized and operate for extended periods at significantly less than full load, there are three significant operational penalties—reduced efficiency, reduced slip (important if the load is a cube-law type), and reduced power factor.

Depending on the motor, efficiency will typically peak at somewhere between 75 percent load and full load. The larger the motor and the higher its peak efficiency, the more likely it will have a relatively flat efficiency curve between 50 percent load and full load, with a hump at 75 percent load some 0.3 to 1 % points higher than at full load. Efficiency drops precipitously below 50 percent load, with the average 100-hp energy efficient motor losing over two points between 50 and 25 percent load and the average 100-hp standard efficiency induction motor dropping some 5.5 points over the same range. Smaller motors lose even more, particularly at lower efficiencies

Decreased Slip can negate efficiency gains
The base motor efficiency is assumed to be 90%.

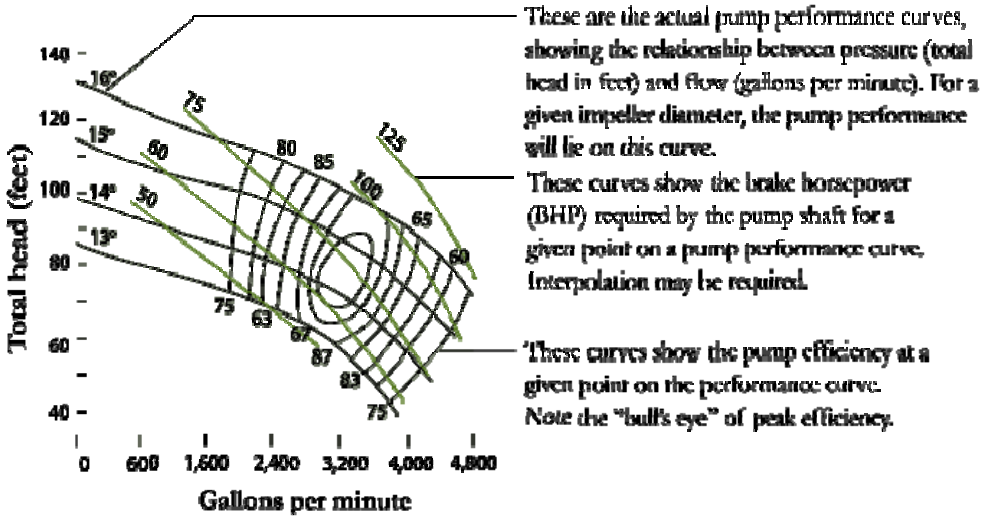


A general rule-of-thumb is that a one percentage point increase in efficiency is equivalent to about a 1/3-point increase in slip—a decrease in slip can therefore quickly negate even a significant energy efficiency improvement (Figure)

Fans and pumps: a special look

Since fans and pumps are the most common motor loads, their operation deserves closer examination. The output of fans and pumps is a struggle between the demands of flow and pressure. In general, the more pressure they provide the less flow, and vice-versa. This relationship can be plotted on a performance curve, as shown in Figure . The result is typically a family of curves, based on different diameter impellers (for pumps) or different blade angles (for fans). Fans and pumps perform optimally in a particular range of flow and pressure head—the bull's eye—and operate less efficiently outside that region.

Typical pump performance curves



8.2.5 Power Distribution Systems

8.2.5.1 Power Distribution System Losses

The Code requires that power cabling be adequately sized as to maintain the distribution losses to not exceed 1% of the total power usage. Maintenance of a record of the design calculation for the losses is also specified.

An engineer or contractor can demonstrate the real savings as well as the advantages of lower generated heat and increased flexibility of the installation with a properly sized distribution system. In addition, when less heat is generated, the result is reduced energy requirements for fans and air conditioning systems.

9 ENERGY SIMULATION

9.1 GENERAL

To show that a building is ECBC compliant using whole building performance, a building energy simulation model using a "standard design" and a "proposed design" needs to be developed. The results of these simulations are compared to see whether the proposed design is more efficient than standard design and ECBC compliant or not. All this process of preparing the standard design model and the proposed case model is explained in this section using a case study. This case study includes the step-by-step procedures followed for an example building located in GandhiNagar, Gujarat, India.

The steps involved for ECBC compliance of any building are:

- Confirmation from the local authority
- Comply with the Mandatory Requirements of the ECBC
- Create the standard design simulation model
- Create the proposed case design simulation model
- Comparing the results from the two models
- Prepare the compliance documents.

All the above steps are individually discussed in detail below to understand the process of preparing models for ECBC compliance.

9.2 CASE STUDY BUILDING - DESCRIPTION

The building consists of eight floors (ground plus seven) with a stilt level parking. This building block on the east side is adjacent to one more building block of the same geometry (See Figure 28). The building's footprint is a square shaped area of 3136 m² (56 m X 56 m). On the ground floor the building activity areas cover a form of 40m X 56m with the long side oriented in east-west direction. The built up area of the building is approx. 24,000 square meters, excluding the stilt level parking, which caters to both the building blocks. The stilt level parking area is semi-exposed and is naturally ventilated.

Figure 28: Building Model with Stilt Level Parking Area& Adjacent Building on the East

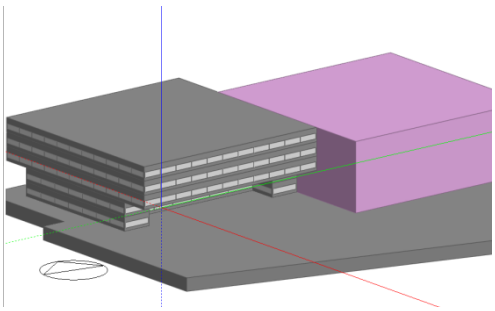
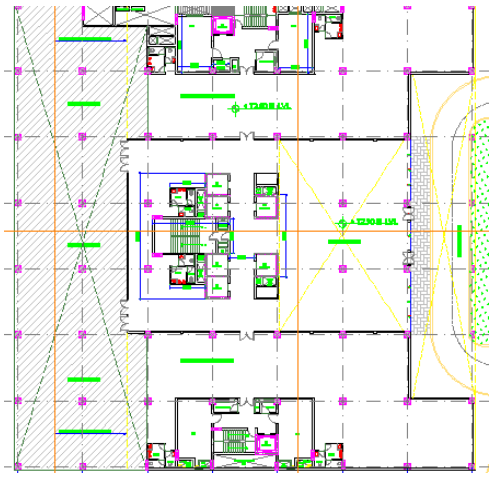
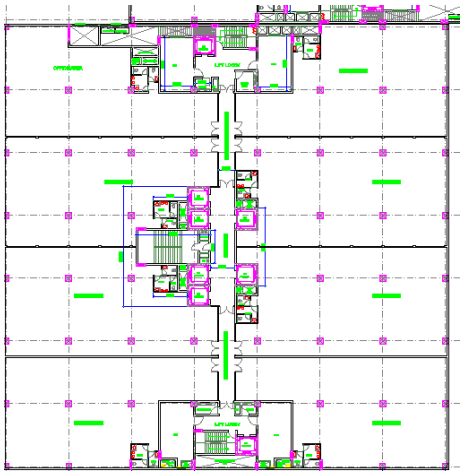


Table 29: Ground Floor Plan of the Case Study Building



The ground floor contains a double height entry lobby with retail areas on either side (See Figure 29). The first floor is allocated for a cafeteria (See Figure 30). Second through seventh floors are typical office floor plans, with office areas towards the north and south facades, which are divided by central core of circulation and vertical transportation areas. The north, south and west facades of the building are the external walls with windows. All windows have single pane reflective glass. The frame for all these windows is an unlabelled thermally unbroken aluminum frame. All the windows have fixed glazing. The east side of the building is in common with the other building block.

Figure 30: First Floor Plan of the Case Study Building



The proposed building will have approximately 80% conditioned area with some proposed unconditioned areas like the staircases. All the external walls are brick construction with stone cladding on the exposed façade. Internal partition walls are designed as brick construction with plaster on both sides. Over deck insulation for the roof will be used to reduce the heat gain through the exposed roof surface.

A high-efficiency electric lighting system will be used throughout the building. Lighting power density on an average is 8.61 W/m² in the office areas and 1.61 W/m² in the stilt level parking.

Water-cooled centrifugal chillers are used for the cooling requirements of the building. All the spaces in the building are served by multi-zone variable air volume (VAV) air handlers, which are connected to a central chiller. The stilt level parking is semi exposed area and is naturally ventilated. Efficient chillers of 570 ton each and with a COP of 6.1 are proposed for the cooling needs of the building.

Appendix E of ECBC classifies GandhiNagar as hot and dry climate. All the characteristics of the building in the standard design model are considered as per its climate classification from the respective tables of building envelope.

A review of the detailed input of both the standard design model and the proposed case model show that the proposed design model does not meet the U-factor standard requirement of the wall as specified in the prescriptive table of the code. Since the frame of the window is unlabeled the resultant U-factor of the complete window assembly is also high when compared with the U-factor of the standard design simulation model. However the internal lighting load is 20% less than the standard in the proposed design model. Also a low SHGC glass is used in the proposed building compared to the standard specified by ECBC.

9.2.1 Step 1: Confirmation from the Local authorities

Before starting to develop the building simulation models to show ECBC compliance, it is advisable to meet the local authorities to confirm whether the building comes under the scope of ECBC and whether it is practically possible for the building to comply with ECBC standard design model in terms of its energy consumption. The following are some of the issues, which are to be confirmed by the local authorities:

- Is ECBC applicable to the building?
- Can this building apply for ECBC compliance and what are the submittal requirements?
- Confirmation of the simulation programs, which can be used for this process of energy simulation to show compliance.
- Any local amendments to the ECBC, which need to be followed.
- Check whether the climate data and the weather file, which is available for the building site is accepted to the authorities.
- What utility rate schedules are approved for calculating energy costs in this jurisdiction?

9.2.2 Step 2: Comply with the Mandatory Provisions

All the mandatory requirements of the ECBC code must be met by the building. The mandatory provisions of building envelope, HVAC, service hot water and pumping, lighting and electrical power are provided in the respective chapters of the code and should be complied by the proposed building. Chapter 4.2, 5.2, 6.2, 7.2 and 8.2 of the ECBC deals with the mandatory provisions, which are to be fulfilled by the building. It may be noted that even if whole building performance approach is adopted for compliance of ECBC, mandatory requirements must be followed. Mandatory requirements are not to be confused with requirements for prescriptive approach.

9.2.3 Step 3: Create the Standard design simulation model

The "standard design" simulation model is created by following Section 11: Appendix B Whole Building Energy Performance of the ECBC. Once the model has been created, the energy consumption of the standard design building is calculated using the simulation model,

Before commencing the data input process for the model, the project should refer to Appendix E- Climate zone map of India in the code to check the climate zone of the building site. The building should then be classified either as a 24-hour activity building or a daytime activity building because the ECBC specifications

for the U-values of the building envelope are mandated according to the climate zone of the building and the occupancy type of the building..

In this particular case, Gandhinagar, Gujrat falls under the Hot-Dry climate zone of India, characteristic of high temperatures, intense solar radiation, clear skies and low precipitation levels. Hot winds are experienced during the day and cool winds at night. Hourly weather data representing information about solar radiation, temperature, humidity, wind speed, wind direction, rainfall, atmospheric pressure, cloud cover, etc. for specific locations are stored in weather files. All simulation programs require the user to select an appropriate weather file for the site location. The simulation program uses the weather data to calculate the heating and cooling loads due to conduction gains and losses, solar gain, heat gained or lost from outside air and humidification or dehumidification.

In cases where the weather file for any particular location is not available for the simulation model, it is advised to use a nearby station/city not more than 2 latitude or 2 longitude (250 kms apart) and within 100m altitude of the actual city location. Weather files for 58 cities from India are available at:

http://www.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region=2_asia_wmo_region_2/country=IND/cname=India

The specifications of standard design simulation model are generated in accordance with the modeling requirements set forth by the ECBC, Table 10.1 of Appendix B. The standard model is created with building specifications (building envelope, HVAC system, lighting, service water heating internal loads etc), that comply with all prescriptive requirements of the ECBC. For example, the building envelope specifications like the orientation and the heat capacity of materials follow the requirements set forth by Table 10.1-4 of Appendix B.

Currently, the ECBC does not mandate any compliance requirements for the thermal performance of underground walls, floors and slab on grade floors in buildings. For these building envelope elements, and other building components currently not regulated by the ECBC, the inputs for the standard design simulation model should be similar to the specifications for the proposed designed. The ASHRAE 90.1-2004 standard may also be used as a reference source to estimate U-values and overall thermal performance guidelines for building envelope components not regulated by the ECBC.

9.2.3.1 Space

For the purposes of this case study, the entire floor plate is assumed to be one conditioned area since the HVAC zoning of the building is not yet designed.

As per ECBC, the classifications of spaces are as follows for the purpose of determining building

envelope requirements.

(a) **Conditioned space:** a cooled space, heated space, or directly conditioned space.

(b) **Semi-heated space:** an enclosed space within a building that is heated by a heating system whose output capacity is greater or equal to 10.7 W/m^2 (3.4 Btu/h-ft^2) of floor area but is not a conditioned space.

(c) An enclosed space within a building that is not conditioned space or a semi-heated space. Crawlspaces, attics, and parking garages with natural or mechanical ventilation are not considered enclosed spaces.

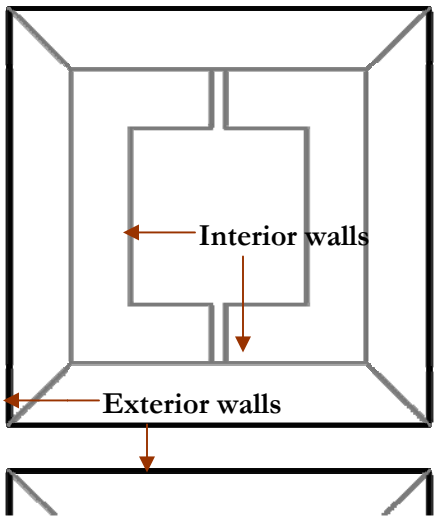
9.2.3.2 Walls

The proposed building in Gandhinagar has two main types of walls, the external walls and the internal partitions (See Figure 31)

The walls of the building should be categorized based on their position within the building. Appendix A of the code under the subhead of Walls deals with the definitions of various kinds of walls in a building. The U-

value of the walls should meet with requirements mentioned in Table 10.1-4 of Appendix B and in the Section 4.3.2 Table 4.2.

Figure 26: Category of Walls in a Typical Floor Plan in the Case Study Building



9.2.3.3 Roof

For the standard design building model the roof requirements are as specified in Table 10.1-4 of Appendix B of the code. This table further refers to Section 4.3.1 Table 4.1 where the U value of the roof assembly is provided depending on the kind of building and the climate it belongs to. Also the required specification of the roof albedo is mentioned in Table 10.1-4 of Appendix B, which says the roof should be modeled with a reflectivity value of 0.3.

9.2.3.4 Windows

Windows in all the directions of the building have the same requirements of SHGC and U value. This U value and the SHGC depend mainly on the window wall ratio WWR and the climate zone thatthe building belongs to. The WWR is the ratio of window area to the total wall area. This WWR is calculated and defined as in Appendix A of the code. The related terms for this window wall ratio as mentioned in Appendix A are the Wall area, gross and the Window wall ratio (WWR). The modeling aspects of the fenestration are specified in Table 10.1-4 of Appendix B of the code. The U value, SHGC and the visible transmittance to the glass are from Table 4.3 of Section 4.3.3 of the code. All the windows in the standard design model of this particular case study have a U value of 3.3 W/sq m K and SHGC of 0.25.

9.2.3.5 Lighting

The lighting power density (LPD) of the standard design model should be defined either using the building area method or the space function method as specified in Table 10.1-5 of Appendix B. The building area method as specified in Section 7.3.2 Table 7.1 of the code, is where an average LPD value is defined for the entire building where as in the space function method as in Section 7.3.3 Table 7.2 of the code, individual spaces are assigned with different LPD values based on the activity within that space.

In this particular case study, the building area method is followed in assigning the input of lighting to the model. The complete building is divided into two major areas, the office and the parking area separately. Table 7.1 of the ECBC is followed in deciding the standard LPD values for the standard design building simulation model.

The LPD in the office areas is 10.8 W/ m2 and in the parking areas it is 3.2 W/m2 for the standard design model of this proposed case study building.

In this case, even though the parking area stilt level is unenclosed and naturally ventilated area, it counts as interior area of the lighting. Therefore this parking area is modeled as an unconditioned semi exterior space with only lighting.

No lighting controls should be modeled in the standard design model of the building.

9.2.3.6 Mechanical

9.2.3.6.1 Defining the mechanical system

The HVAC system of the standard design model is decided based on the following as specified in Table 10.2 of Appendix B of the code.The HVAC system type and performance criteria depend on the following two categories:-

- The occupancy type of the building (residential or non residential category)
- The number of floor and total built-up area(minus the parking area of the building)

Depending on the above two categories the standard design building model should be served by a water cooled chiller with a variable air volume (VAV) AHU for each zone along a electric resistance heating source.

In the proposed design there is no heating system being provided for the building, however since the standard design building should also be modeled with heating, the same kind of provision is assumed for the proposed design simulation model too.

9.2.3.6.2 Fans and controls

As specified in the mandatory provisions as in Section 5.2.3, all the mechanical cooling and heating systems shall be controlled by respective schedules and set-point temperatures.

The supply fans should be controlled by variable speed drives as specified by the standard in Section 5.3.2.

9.2.3.6.3 Chiller sizing

The sizes of the chiller which decides the COP of the chiller as per Table 5.1 of Section 5.2.2 of the code is considered from the following table (See Table 3434).

Table 34: Chiller Sizing for the Case Study Building

Tonnage	Chillers
<=600 tons	1 centrifugal chiller
>600 tons &<= 1200 tons	2 centrifugal chiller equally sized
>1200 tons	Multiple centrifugal chillers equally sized Each chiller not greater than 800 tons.

To determine the sizes of the chiller, a sizing run of the standard design model is performed. The sizing ratios for this model would be 15% oversized for the cooling and 25% oversized for the heating unit as mentioned in the code.

Depending of the tonnage of the each chiller, the COP of the chiller is selected from Table 5.1 of Section 5.2.2 of the code. Since some of the values given in this table are aspirational values, these specific values will be followed as in ASHRAE 90.1-2004.

For this case study building in Gujarat, since the sizing run gave XXX TR as chiller capacity, the COP of the chiller in the standard design model will be 6.1.

Any other values or details of the HVAC would be as specified in Table 10.1 and Table 10.2 of Appendix B. Any values which are not specified by the code will be followed from ASHRAE 90.1-2004 Appendix G. All the values which both ECBC and ASHRAE 90.1-2004 are silent about will be as modeled same as in the proposed case model.

9.2.4 Step 4: Create the Proposed design Simulation Model

The proposed design simulation model captures all the features of the proposed design. The building simulation model should appropriately incorporate all the energy related features of the proposed building design. Certain approximations in creating the geometry of the model are allowed. However, with the available information, within the available time and with the minimum number of approximations, the most accurate model is to be prepared by selected software which has all features as specified by the code. The selection of the software should be done based on the specification of the code as in Section 10.2.1 of Appendix B. All the allowed types of approximations are explained within the code itself.

9.2.4.1 Building Envelope

All the walls which are within 45 degrees of each other can be combined into a single wall having the same orientation. All the thermal properties of the building envelope need to be correctly defined in the model. Definitions of walls must include thermal mass (specific heat and density) as well as resistance to heat flow (U-factor or R-value).Wall assemblies in the simulation model have to be built up out of a library of physical properties for different building materials (See Figure 32).

Figure 32: Wall Cross Section of the Case Study Building as Shown in the Software

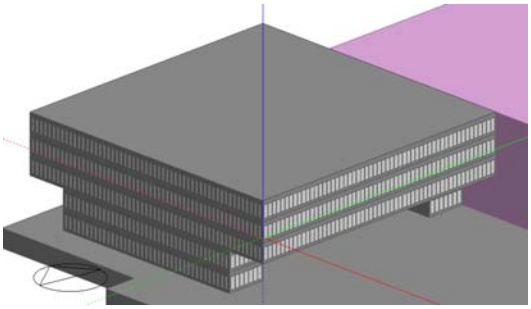
The external wall section of this building proposed in Gujarat is a combination of 230mm brick with plaster on either side. On the external surface of the wall granite stone cladding is done in most of the areas of the facades. If the material properties and R-values are provided by the manufacturer, they must be combined together to calculate the complete U-value of the construction. In this case study the specified materials are available in the simulation software library, which are combined to form the required construction. The resultant U-value of the wall is 1.75 W/m^2K (See Figure 33).

Figure 33: U-Value of the External Wall of the Case Study Building as Calculated by the Energy Simulation Tool

Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	2.487
R-Value (m2-K/W)	0.572
U-Value (W/m2-K)	**1.748**
With Bridging (BS EN ISO 6946)	
Upper resistance limit (m2-K/W)	0.572
Lower resistance limit (m2-K/W)	0.572
U-Value surface to surface (W/m2-K)	2.487
R-Value (m2-K/W)	0.572
U-Value (W/m2-K)	**1.748**

The simulation program used will have libraries of many common building materials. As shown in the above figure all the properties of each material are considered in calculating the final U value of the total composition. The software also includes the air film resistance in calculating the U value.

Figure 34: Glazing Spread Distribution on the Walls in the Proposed Case



While modeling the facades of the building, the total window area on each orientation of the building (N, S, E or W) can be considered as one single data input; as opposed to inputting separate windows as unique data entries in the simulation model. However, if the building uses any daylight controls or there are differences in shading devices, the windows need to be modeled separately as individualized and unique building elements.

In this case study, windows are spread on the external wall in the existing ratios as calculated from the proposed design. (See Figure 34) Manually operated window-shading devices such as blinds or shades are not required to be modeled. However, any permanent shading devices such as fins, overhangs, and light-shelves are required to be modeled, as they have a significant impact on the overall heat gain into the building.

The project does not use any labeled window frame, so the project's proposed design needs to comply with the requirement of the ECBC standard as specified in Table 11.1 of Appendix C. As per the standard the U-value of the window assembly is 7.1 W/m^2K. The SHGC of the glass is 0.20(as given by the manufacturer, since the glass is labeled) and the visible transmittance is 0.22 as in the original proposed design.

The simulation model should also include an accurate definition of the floor slab and the roof assembly, including specification of the thermal mass (specific heat and density) as well as resistance to heat flow (U-factor or R-value).For exterior roofs other than roofs with ventilated attics, the reflectance and emittance of the proposed roof surface (provided with the building material specifications) shall also be modeled. The reflectance and emittance shall be tested in accordance with Section 4.3.1.1 of ECBC.

9.2.4.2 Lighting

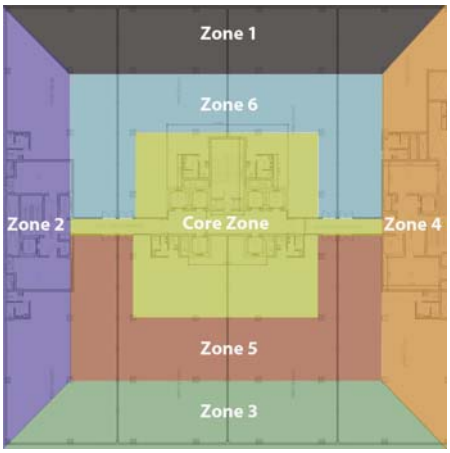
The installed electric lighting power designed for the proposed design should be modeled accurately in the proposed design simulation model. This lighting power density generally differs from the standard value specified in the code. The lighting power should include the power consumed by ballasts as well as the lamps.The lighting system power in the simulation model should include all lighting system components shown or provided for on plans (including lamps, ballasts, task fixtures, and furniture-mounted fixtures).

This building in Gandhinagar has an LPD value of 8.61 W/m^2K in the office areas and 1.61 W/m^2K in the parking areas. There are no daylight sensors proposed in the design the lighting systems for this building. However, in cases where the electrical design for the proposed building included lighting controls, they should be included in the simulation model.

9.2.4.3 HVAC

The HVAC system in the proposed design simulation model should be specified according to the suggested mechanical design layout. All the inputs should be as per the designs, which include the fan and equipment efficiencies, static pressure, pump heads, etc. None of the default values by the software should be considered as the input values for these parameters of HVAC. The office building is served by a VAV handling unit, which is served by a centrifugal chiller. Since the internal HVAC design and zoning of the proposed building is not yet done, a perimeter and core zone model with simplified zoning is considered in both the proposed and standard design simulation models. In cases where the HVAC zoning is not designed, the code suggests that "a simple zoning is to be done such that the complete floor plate would be considered as conditioned area and the perimeter areas (minimum till 4.5 meter from exterior wall) in different orientations would be considered as different thermal blocks with a central core area. This zoning pattern will be same for both proposed case design model and the standard design model."

Figure 35: Simplified Zoning of the Case Study Building When HVAC Zoning Not Designed



In this case study of the proposed building, the HVAC zoning is not yet designed. Therefore a perimeter and core zoning following the 8m x 8m grid of the building has been used in the simulation model. **Error! Reference source not found.**5 shows the considered zoning pattern of a typical floor.

HVAC ZONING FOR ENERGY SIMULATION

Energy simulation of any building should only be undertaken after the HVAC system and all its specifications have been finalized, as this has a major influence on the energy performance of the building.

The representative perimeter and core HVAC zoning scheme used to simulate this case study building has been adopted only due to the non-availability of the zoning scheme for the proposed building. The 'perimeter-and-core' zoning technique simplifies the data input process but does not represent standard energy simulation procedure, nor does is this technique representative of energy-modelling/HVAC zoning best practices.

Zoning an HVAC system allows the ability to set individualized mechanical performance schedules and temperature controls for different zones. It is recommended that HVAC zones should be designed according to the orientation of the spaces, heating/cooling loads variations, activity levels, occupancy schedules and unique temperature requirements for different parts of the building (For example, lower temperature set points for overheated computer or equipment rooms etc.)

In cases where a complete HVAC system has been designed for the proposed building, the simulation model should be consistent with the design documents. It should reflect the actual zoning scheme, system type and all actual component capacities and efficiencies. Any HVAC specific energy-efficiency features (example, economizers, variable-air-volume drives etc.) should also be included in the simulation model as per the specifications of the design documents.

The schedules of the building can be prepared by the energy analyst to approximately represent the actual use of the proposed design building. The schedules being used should be the same for both the standard design and the proposed design simulation models.

There are two major differences in modeling the standard design model and the proposed case model. The standard design differs from the proposed design model in terms of building envelope U-values, glazing SHGC, lighting power densities, and mechanical efficiencies of HVAC systems.

The other major difference in the building modeling will be the modeling of the glazing. In the standard design the glazing WWR is spread on all the façades equally as specified in Table 10.1 -4 of Appendix B. In this base line building there is no self shading of the building allowed as specified in Table 10.1-4 of Appendix B. No assumed efficiency measures should be modeled over the proposed design to meet the standard design or to perform better than standard design. However, efficiency options designed for implementation in the proposed building can be included in the proposed design simulation model.

9.2.5 Step 5: Completing and comparing the models

Both the proposed design model and the standard design simulation models are run and the results are analyzed to check for errors. In some cases, there are unmet hours generated which state the hours in a year which are of discomfort either due to cooling or the heating. They are normally categorized either as the system unmet or the plant unmet hours, which state the number of hours either the system or the plant was unable to meet the loads on them respectively.

This is commonly found in morning start-up situations where the pick-up loads cannot be met in a single hour. If the number of hours that loads are unmet by either the systems or plant differs by more than 50 hours between the standard design and proposed design models, these simulation results will not be accepted as valid. The best way to deal with this problem is to confirm that the sizing method of both the standard design and proposed system is similar. Alternatively, these results may indicate that some part of the HVAC system is undersized and may require redesign. These models are refined and re-run and checked for all the compliance clauses again and if found in order, prepared to compliance documentation checks.

9.2.6 Step 6: Documentation of the Compliance Process

For the project to finally comply with the code, the required compliance documents should be prepared and filed to show that the proposed design consumes less or equal energy than the standard design model.

Given below are tables showing a comparison of the data inputs used to generate the standard and the proposed design simulation model for this particular case study building in Gandhinagar, Gujarat.

Table 30: Activity

	Proposed Building	Standard Design
Occupancy	All zones:70 sq ft/ person	All zones:70 sq ft/ person
	Schedule: 8am-8pm	Schedule: 8am-8pm
	One central zone (lobby areas): 500 sq ft/person	One central zone (lobby areas): 500 sq ft/person
Activity	Office	Office
Holiday	Additional holidays 12	Additional holidays 12
DHW consumption rate	0	0
Cooling	Setpoint:23 ^{0}C	Setpoint: 23 ^{0}C
Office equipment	4 W/sq ft	4 W/sq ft
	**Schedule: 8am-8pm	**Schedule: 8am-8pm

Miscelleneous	None	None
Catering	None	None

Table 31: Construction

	Proposed Building	Standard Design
External walls	0.5" stone cladding+0.5" Plaster+9"Clay brick +0.5" Plastering [outside to inside] U value= 1.75 W/sq m K	0.5" Plaster+9"Clay brick +insulation +0.5" Plastering [outside to inside] U value= 0.44 W/sq m K
Flat roof	Overdeck insulation+RCC 4" Slab+0.5" plastering [outside to inside] U value=0.072 Btu/sq ft F (0.409 W/sq m K)	Overdeck insulation+RCC 4" Slab+0.5" plastering [outside to inside] U value=0.072 Btu/sq ft F (0.409 W/sq m K)
Internal partitions	0.5" Plaster+9"Clay brick +0.5" Plastering U value=0.419 Btu/sq ft F (2.38 W/sq m K)	0.5" Plaster+9"Clay brick +0.5" Plastering U value=0.419 Btu/sq ft F (2.38 W/sq m K)
Ground floor	1" plastering+RCC 4" Slab (outside to inside) U value=0.630 Btu/sq ft F (3.58 W/sq m K)	1" plastering+RCC 4" Slab+insulation+0.5" plastering (outside to inside) U value=0.350 Btu/sq ft F (1.99 W/sq m K)
Internal floor	RCC 4" Slab +0.5" plastering + 0.5" Ceramic tiles (outside to inside) U value=0.641 Btu/sq ft F (3.64 W/sq m K)	1" plastering+RCC 4" Slab+insulation+0.5" plastering (outside to inside) U value=0.350 Btu/sq ft F (1.99 W/sq m K)
Airtightness	0.2 ACH	0.2 ACH

Table 32: Openings

	Proposed Building	Standard Design
Layout	39.7% glazing as per the drawings	40% glazing as per the drawings
Height of the window	7.87'-effectively	7.87'-effectively
Window spacing	3.28'	3.28'
Sill height	1.72'	1.72'
Glass	U value:1.22 Btu/sq ft F (Since Unlabeled U value as per ECBC-1.25 Btu/sq ft F, closest one selected from DB library)	U value:0.573
	SHGC:0.33	SHGC:0.244
	VLT:0.22	VLT:0.232
Frames and dividers	Not model as the frame is unlabeled, U value of glazing is U value of the assembly.	Base case glazing U value is of complete assembly
	No dividers	No dividers
Shading	Internal:None	Internal:None
	External:None	External:None

Doors	None	None
Vents	None	None

Table 33: Lighting

	Proposed Building	Standard Design
Lighting power density	Conditioned rooms: 2.5 W/sq ft	Conditioned rooms: 1 W/sq ft (10.8 W/sq m)
	Parking: 1 W/sq ft	Parking: 0.3 W/sq ft (3.2 W/sq m)
Luminarie type	Recessed	Recessed
Task lighting	None	None
Lighting control	None	None
Motion sensors	In all the areas	In all the areas

Table 34: HVAC

	Proposed Building	Standard Design
System type	CAV	VAV
MECHANICAL VENTILATION		
Rate	6 ac/h	6 ac/h
Night cycle control	Stay off	cycle on
Fan placement	Draw through	Draw through
Part-load power coefficients	Inlet vane dampers	Inlet vane dampers
Fan type	Intake	Intake
Pressure rise in water	2 inch	2 inch
Total efficiency [%]	80	80
Fan in air [%]	90	90
Economizer	NA	NA
Heat recovery	NA	NA
Heating	NA	NA
Cooling		
Precool	0.5 hrs	0.5 hrs
Chiller COP	5	6.1
Cooling distribution loss (%)	5%	5%
Off coil set point temperature	57.20	57.20
Air temperature distribution	Mixed	Mixed

Table 40: Schedule – 8 am to 8 pm working

Time	Occupancy
8am-9am	25%
9am-10m	90%
10am-11am	100%
11am-12noon	100%

12noon-1am	70%
1pm-2pm	30%
2pm-3pm	50%
3pm-4pm	90%
4pm-5pm	95%
5pm-6pm	95%
6pm-7pm	80%
7pm-8pm	25%

10 ECBC DEFINITIONS, ABBREVIATIONS AND ACRONYMS

10.1 GENERAL

Certain terms, abbreviations, and acronyms are defined in this section for the purposes of this code. These definitions are applicable to all sections of this code. Terms that are not defined shall have their ordinarily accepted meanings within context in which they are used. Webster's Third New International Dictionary of the English Language, Unabridged, copyright 1986, shall be considered as providing ordinarily accepted meanings.

10.2 DEFINITIONS

Addition: an extension or increase in floor area or height of a building outside of the existing building envelope

Alteration: any change, rearrangement, replacement, or addition to a building or its systems and equipment; any modification in construction or building equipment

Annual fuel utilization efficiency (AFUE): an efficiency description of the ratio of annual output energy to annual input energy as developed in accordance with requirements of U.S. Department of Energy (DOE) 10CFR Part 430

Astronomical time switch: an automatic time switch that makes an adjustment for the length of the day as it varies over the year

Authority having jurisdiction: the agency or agent responsible for enforcing this Code

Automatic: self-acting, operating by its own mechanism when actuated by some non-manual influence, such as a change in current strength, pressure, temperature, or mechanical configuration.

Automatic control device: a device capable of automatically turning loads off and on without manual intervention

Balancing, air system: adjusting airflow rates through air distribution system devices, such as fans and diffusers, by manually adjusting the position of dampers, splitters vanes, extractors, etc., or by using automatic control devices, such as constant air volume or variable air volume boxes

Balancing, hydronic system: adjusting water flow rates through hydronic distribution system devices, such as pumps and coils, by manually adjusting the position valves, or by using automatic control devices, such as automatic flow control valves

Ballast: a device used in conjunction with an electric-discharge lamp to cause the lamp to start and operate under proper circuit conations of voltage, current, waveform, electrode heat, etc.

Boiler: a self-contained low-pressure appliance for supplying steam or hot water

Boiler, packaged: a boiler that is shipped complete with heating equipment, mechanical draft equipment, and automatic controls; usually shipped in one or more sections. A packaged boiler includes factory-built boilers manufactured as a unit or system, disassembled for shipment, and reassembled at the site.

Building: a structure wholly or partially enclosed within exterior walls, or within exterior and party walls, and a roof, affording shelter to persons, animals, or property.

Building, existing: a building or portion thereof that was previously occupied or approved for occupancy by the authority having jurisdiction

Building complex: a group of buildings in a contiguous area under single ownership

Building entrance: any doorway, set of doors, turnstiles, or other form of portal that is ordinarily used to gain access to the building by its users and occupants

Building envelope: the exterior plus the semi-exterior portions of a building. For the purposes of determining building envelope requirements, the classifications are defined as follows:

Building envelope, exterior: the elements of a building that separate conditioned spaces from the exterior

Building envelope, semi-exterior: the elements of a building that separate conditioned space from unconditioned space or that enclose semi-heated spaces through which thermal energy may be transferred to or from the exterior, or to or from unconditioned spaces, or to or from conditioned spaces

Building exit: any doorway, set of doors, or other form of portal that is ordinarily used only for emergency egress or convenience exit

Building grounds lighting: lighting provided through a building's electrical service for parking lot, site, roadway, pedestrian pathway, loading dock, and security applications

Building material: any element of the building envelope through which heat flows and that heat is included in the component U-factor calculations other than air films and insulation

Circuit breaker: a device designed to open and close a circuit by nonautomatic means and to open the circuit automatically at a predetermined over-current without damage to itself when properly applied within its rating

Class of construction: for the building envelope, a subcategory of roof, wall, floor, slab-on-grade floor, opaque door, vertical fenestration, or skylight

Coefficient Of Performance (COP) – cooling: the ratio of the rate of heat removal to the rate of energy input, in consistent units, for a complete refrigerating system or some specific portion of that system under designated operating conditions

Coefficient Of Performance (COP) – heating: the ratio of the rate of heat delivered to the rate of energy input, in consistent units, for a complete heat pump system, including the compressor and, if applicable, auxiliary heat, under designated operating conditions

Commercial building: all buildings except for multi-family buildings of three stories or fewer above grade and single-family buildings

Construction documents: drawings and specifications used to construct a building, building systems, or portions thereof

Control: to regulate the operation of equipment

Control device: a specialized device used to regulate the operation of equipment

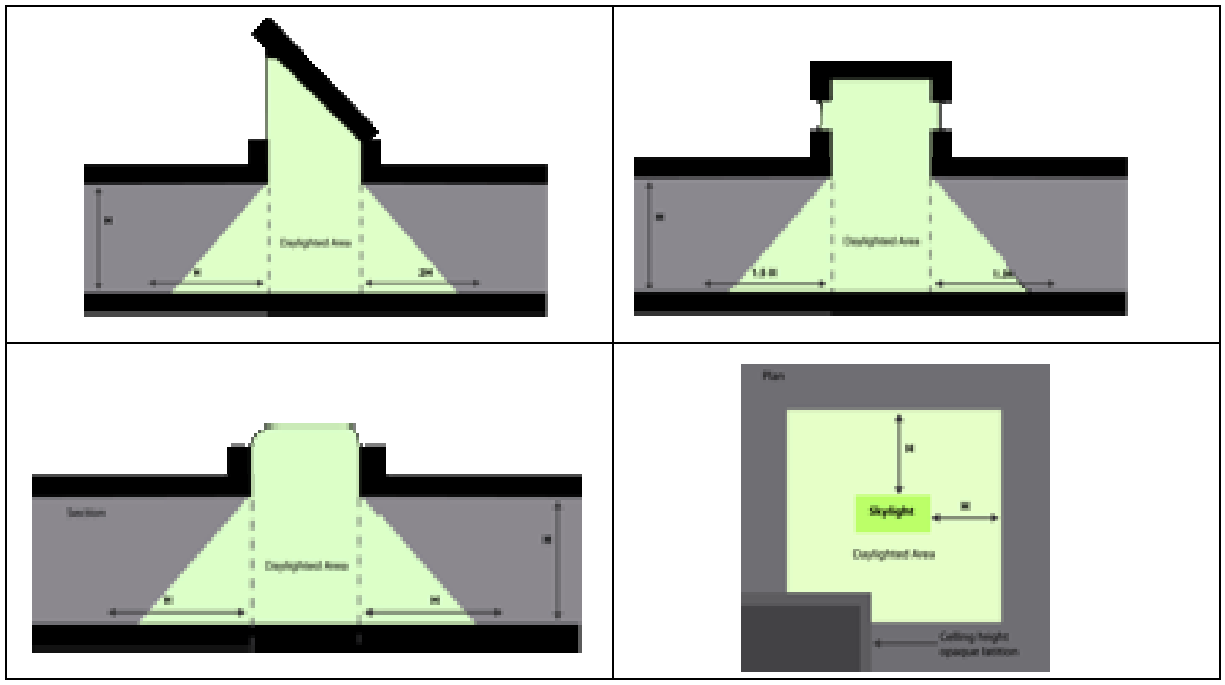
Constant Volume System: A space-conditioning system that delivers a fixed amount of air to each space. The volume of air is set during the system commissioning.

Cool roof: a property of a surface that describes its ability to reflect and reject heat. Cool roof surfaces have both a light color (high solar reflectance) and a high emittance (can reject heat back to the environment)

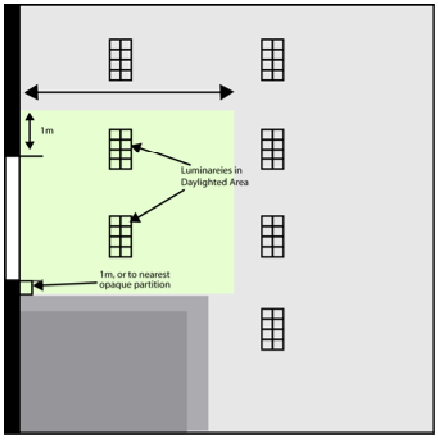
Daylighted area: the daylight illuminated floor area under horizontal fenestration (skylight) or adjacent to vertical fenestration (window), described as follows

Effective Aperture: Visible Light Transmittance x Window-to-Wall Ratio (EA = VLT x WWR).

Horizontal Fenestration: the area under a skylight, monitor, or sawtooth configuration with an effective aperture greater than 0.001 (0.1%). The daylighted area is calculated as the horizontal dimension in each direction equal to the top aperture dimension in that direction plus either the floor-to-ceiling height (H) for skylights, or 1.5 H for monitors, or H or 2H for the sawtooth configuration, or the distance to the nearest 1000 mm (42 in) or higher opaque partition, or one-half the distance to an adjacent skylight or vertical glazing, whichever is least, as shown in the plan and section figures below.



Vertical Fenestration: the floor area adjacent to side apertures (vertical fenestration in walls) with an effective aperture greater than 0.06 (6%). The daylighted area extends into the space perpendicular to the side aperture a distance either two times the head height of the side aperture or to the nearest 1.35 m (54 in) or higher opaque partition, whichever is less. In the direction parallel to the window, the daylighted area extends a horizontal dimension equal to the width of the window plus either 1 m (3.3 ft) on each side of the aperture, the distance to an opaque partition, or one-half the distance to an adjacent skylight or window, whichever is least.



Dead band: the range of values within which a sensed variable can vary without initiating a change in the controlled process

Demand: the highest amount of power (average Btu/h over an interval) recorded for a building or facility in a selected time frame

Design capacity: output capacity of a system or piece of equipment at design conditions

Design conditions: specified environmental conditions, such as temperature and light intensity, required to be produced and maintained by a system and under which the system must operate

Distribution system: a device or group of devices or other means by which the conductors of a circuit can be disconnected from their source of supply

Door: all operable opening areas (which are not fenestration) in the building envelope, including swinging and roll-up doors, fire doors, and access hatches. Doors that are more than one-half glass are considered fenestration. For the purposes of determining building envelope requirements, the classifications are defined as follows:

Door, non-swinging*:* roll-up sliding, and all other doors that are not swinging doors.

Door, swinging: all operable opaque panels with hinges on one side and opaque revolving doors.

Door area: total area of the door measured using the rough opening and including the door slab and the frame.

Dwelling unit: a single unit providing complete independent living facilities for one or more persons, including permanent provisions for living, sleeping, eating, coking, and sanitation

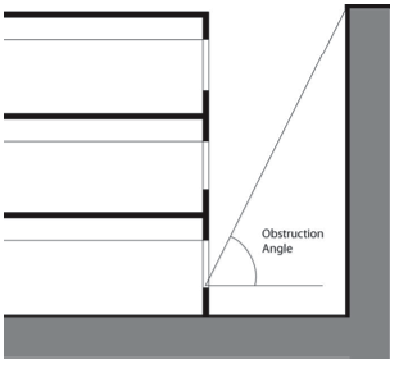
Economizer, air: a duct and damper arrangement and automatic control system that together allow a cooling system to supply outdoor air to reduce or eliminate the need for mechanical cooling during mild or cold weather

Economizer, water: a system by which the supply air of a cooling system is cooled indirectly with water that is itself cooled by heat or mass transfer to the environment without the use of mechanical cooling

Effective aperture: Visible Light Transmittance x Window-to-wall Ratio. (EA = VLT x WWR)

Effective aperture, horizontal fenestration: a measure of the amount of daylight that enters a space through horizontal fenestration (skylights). It is the ratio of the skylight area times the visible light transmission divided by the gross roof area above the daylighted area. *See also daylighted area.*

Effective aperture, vertical fenestration: a measure of the amount of daylight that enters a space through vertical fenestration. It is the ratio of the daylight window area times its visible light transmission plus half the vision glass area times its visible light transmission and the sum is divided by the gross wall area. Daylighted window area is located 2.2 m (7 ft) or more above the floor and vision window area is located above 1 m (3 ft) but below 2.2 m (7 ft). The window area, for the purposes of determining effective aperture shall not include windows located in light wells when the angle of obstruction (α) of objects obscuring the sky dome is greater than 70^{o}, measured from the horizontal, nor shall it include window area located below a height of 1 m (3 ft). *See also daylighted area.*



Efficacy: the lumens produced by a lamp/ballast system divided by the total watts of input power (including the ballast), expressed in lumens per watt

Efficiency: performance at a specified rating condition

Remittance: the ratio of the radiant heat flux emitted by a specimen to that emitted by a blackbody at the same temperature and under the same conditions

Enclosed building: a building that is totally enclosed by walls, floors, roofs, and openable devices such as doors and operable windows

Energy: the capacity for doing work. It takes a number of forms that may be transformed from one into another such as thermal (heat), mechanical (work), electrical, and chemical. Customary measurements are watts (W)

Energy Efficiency Ratio (EER): Performance of smaller chillers and rooftop units is frequently measured in EER rather than kW/ton. It is the ratio of net cooling capacity in Btu/h to total rate of electric input in watts under designated operating conditions. The higher the EER, the more efficient the unit

Energy Factor (EF): a measure of water heater overall efficiency

Envelope performance factor: The trade-off value for the building envelope performance compliance option calculated using the procedures specified in Section 12-Appendix D. For the purposes of determining building envelope requirements the classifications are defined as follows:

Base envelope performance factor: the building envelope performance factor for the base design

Proposed envelope performance factor: the building envelope performance factor for the proposed design

Equipment: devices for comfort conditioned, electric power, lighting, transportation, or service water heating including, but not limited to, furnaces, boilers, air conditioners, heat pumps, chillers, water heaters, lamps, luminaries, ballasts, elevators, escalators, or other devices or installations

Equipment, existing: equipment previously installed in an existing building

Facade area: area of the façade, including overhanging soffits, cornices, and protruding columns, measured in elevation in a vertical plane, parallel to the plane of the face of the building. Non-horizontal roof surfaces shall be included in the calculations of vertical façade area by measuring the area in a plane parallel to the surface.

Fan system power: the sum of the nominal power demand (nameplate W or HP) of motors of all fans that are required to operate at design conditions to supply air from the heating or cooling source to the conditioned space(s) and return it to the source of exhaust it to the outdoors.

Fenestration: all areas (including the frames) in the building envelope that let in light, including windows, plastic panels, clerestories, skylights, glass doors that are more than one-half glass, and glass block walls.

Skylight: a fenestration surface having a slope of less than 60 degrees from the horizontal plane. Other fenestration, even if mounted on the roof of a building, is considered vertical fenestration.

Vertical fenestration*:* all fenestration other than skylights. Trombe wall assemblies, where glazing is installed within 300 mm (12 in) of a mass wall, are considered walls, not fenestration.

Fenestration area: total area of the fenestration measured using the rough opening and including the glazing, sash, and frame. For doors where the glazed vision area is less than 50% of the door area, the fenestration area is the glazed vision area. For all other doors, the fenestration area is the door area.

Floor area gross: the sum of the floor areas of the spaces within the building including basements, mezzanine and intermediate-floored tiers, and penthouses with headroom height of 2.5 m (7.5 ft) or greater. It is measured from the exterior faces of exterior walls or from the centerline of walls separating buildings, but excluding covered walkways, open roofed-over areas, porches and similar spaces, pipe trenches, exterior terraces or steps, chimneys, roof overhangs, and similar features.

Gross building envelope floor area: the gross floor area of the building envelope, but excluding slab-on-grade floors.

Gross conditioned floor area: the gross floor area of conditioned spaces

Gross lighted floor area*:* the gross floor area of lighted spaces.

Gross semi heated floor area: the gross floor area of semi heated spaces.

Flue damper: a device in the flue outlet or in the inlet of or upstream of the draft control device of an individual, automatically operated, fossil fuel-fired appliance that is designed to automatically open the flue outlet during appliance operation and to automatically close the flue outlet when then appliance is in standby condition.

Fossil fuel: fuel derived from a hydrocarbon deposit such as petroleum, coal, or natural gas derived from living matter of a previous geologic time.

Fuel: a material that may be used to produce heat or generate power by combustion.

Generally accepted engineer standard: a specification, rule, guide, or procedure in the field of engineering, or related thereto, recognized and accepted as authoritative.

Grade: the finished ground level adjoining a building at all exterior walls.

Guest room: any room or rooms used or intended to be used by a guest for sleeping purposes.

Heat capacity: the amount of heat necessary to raise the temperature of a given mass 1°C (1°F). Numerically, the heat capacity per unit area of surface (W/m²-°C [Btu/ft²-°F]) is the sum of the products of the mass per unit area of each individual material in the roof, wall, or floor surface multiplied by its individual specific heat.

Heat Pump: A heat pump consists of one or more factory-made assemblies that normally include indoor conditioning coil, compressor, and outdoor coil, including means to provide a heating function. Heat pumps provide the function of air heating with controlled temperature, and may include the functions of air cooling, air circulation, air cleaning, dehumidifying, or humidifying.

Heating Seasonal Performance Factor (HSPF): the total heating output of a heat pump during its normal annual usage period for heating (in Btu) divided by the total electric energy input during the same period.

Historic: a building or space that has been specifically designed as historically significant.

HVAC system: the equipment, distribution systems, and terminals that provide, either collectively or individually, the processes of heating, ventilating, or air conditioned to a building or portion of a building.

Infiltration: the uncontrolled inward air leakage through cracks and crevices in any building element and around windows and doors of a building caused by pressure differences across these elements due to factors such as wind, inside and outside temperature differences (stack effect), and imbalance between supply and exhaust air systems.

Installed interior lighting power: the power in watts of all permanently installed general, task, and furniture lighting systems and luminaires.

Integrated part-load value: a single number figure of merit based on part-load EER, COP, or KW/ton expressing part-load efficiency for air-conditioning and heat pump equipment on the basis of weighted operation at various load capacities for the equipment.

Kilovolt-ampere: where the term "kilovolt-ampere" (kVA) is used in this Code, it is the product of the line current (amperes) times the nominal system voltage (kilovolts) times 1.732 for three-phase currents. For single-phase applications, kVA is the product of the line current (amperes) times the nominal system voltage (kilovolts).

Kilowatt: the basic unit of electric power, equal to 1000 W.

Labeled: equipment or materials to which a symbol or other identifying mark has been attached by the manufacturer indicating compliance with specified standard or performance in a specified manner.

Lamp: a generic term for man-made light source often called bulb or tube.

Lighted floor area, gross: the gross floor area of lighted spaces.

Lighting, decorative: lighting that is purely ornamental and installed for aesthetic effect. Decorative lighting shall not include general lighting.

Lighting, emergency: lighting that provides illumination only when there is a general lighting failure.

Lighting, general: lighting that provides a substantially uniform level of illumination throughout an area. General lighting shall not include decorative lighting or lighting that provides a dissimilar level of illumination to serve a specialized application or feature within such area.

Lighting Efficacy (LE): the quotient of the total lumens emitted from a lamp or lamp/ballast combination divided by the watts of input power, expressed in lumens per watt.

Lighting system: a group of luminaires circuited or controlled to perform a specific function.

Lighting power allowance:

Interior lighting power allowance: the maximum lighting power in watts allowed for the interior of a building

Exterior lighting power allowance: the maximum lighting power in watts allowed for the exterior of a building

Lighting Power Density (LPD): the maximum lighting power per unit of area of a building classification of space function.

Low-rise residential: single-family houses, multi-family structures of three stories or fewer above grade, manufactured houses (mobile homes), and manufactured houses (modular).

Lumen: It is the unit of total light output from a light source. If a lamp or fixture were surrounded by a transparent bubble; the total light flow through the bubble is measured in lumens. Lamps are rated in lumens, which is the total amount of light they emit, not their brightness and not the light level on a surface. Typical indoor lamps have light output ranging from 50 to 10,000 lumens. Lumen value is used for purchasing and comparing lamps and their outputs. Lumen output of a lamp is not related to the light distribution pattern of a lamp.

Luminaries: a complete lighting unit consisting of a lamp or lamps together with the housing designed to distribute the light, position and protect the lamps, and connect the lamps to the power supply.

Manual (non-automatic): requiring personal intervention for control. Non-automatic does not necessarily imply a manual controller, only that personal intervention is necessary.

Manufacturer: the company engaged in the original production and assembly of products or equipment or a company that purchases such products and equipment manufactured in accordance with company specifications.

Mean temperature: one-half the sum of the minimum daily temperature and maximum daily temperature.

Mechanical cooling: reducing the temperature of a gas or liquid by using vapor compression, absorption, and desiccant dehumidification combined with evaporative cooling, or another energy-driven thermodynamic cycle. Indirect of direct evaporative cooling alone is not considered mechanical cooling.

Metering: instruments that measure electric voltage, current, power, etc.

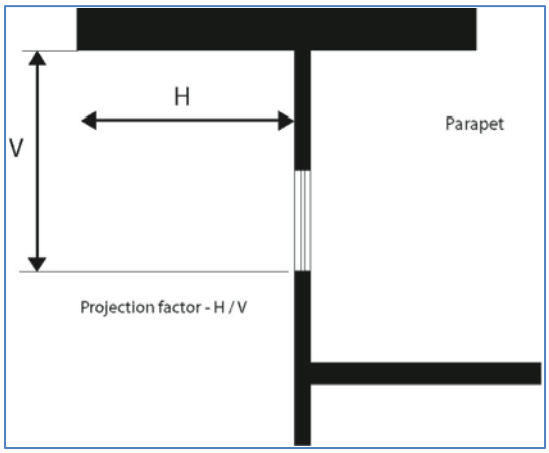
Multifamily high-rise: multifamily structures of four or more stories above grade

Multifamily low-rise: multifamily structures of three or less stories above grade

Multiplication factor: indicates the relative reduction in annual solar cooling load from overhangs and/or side fins with given projection factors, relative to the respective horizontal and vertical fenestration dimensions.

Non-automatic: see *definition of manual.*

Occupancy sensor: a device that detects the presence or absence of people within an area and causes lighting, equipment, or appliances to be regulated accordingly.



Opaque: all areas in the building envelope, except fenestration and building service openings such as vents and grilles.

Orientation: the direction an envelope element faces, i.e., the direction of a vector perpendicular to and pointing away from the surface outside of the element. For vertical fenestration, the two categories are north-oriented and all other.

Outdoor (outside) air: air that is outside the building envelope or is taken from the outside the building that has not been previously circulated through the building.

Overcurrent: any current in excess of the rated current of the equipment of the capacity of the conductor. It may result from overload, short circuit, or ground fault.

Packaged Terminal Air Conditioner (PTAC): a factory-selected wall sleeve and separate unencased combination of heating and cooling components, assemblies, or sections. It may include heating capability by hot water, steam, or electricity, and is intended for mounting through the wall to service a single room or zone.

Party wall: a firewall on an interior lot line used or adapted for joint service between two buildings.

Permanently installed: equipment that is fixed in place and is not portable or movable.

Plenum: a compartment or chamber to which one or more ducts are connected, that forms a part of the air distribution system, and that is not used for occupancy or storage. A plenum often is formed in part or in total by portions for the building.

Pool: any structure, basin, or tank containing an artificial body of water for swimming, diving, or recreational bathing. The terms include, but not limited to, swimming pool, whirlpool, spa, hot tub.

Process load: the load on a building resulting from the consumption or release of process energy.

Projection factor, overhang: the ratio of the horizontal depth of the external shading projection divided by the sum of the height of the fenestration and the distance from the top of the fenestration to the bottom of the farthest point of the external shading projection, in consistent units.

Projection factor, sidefin: the ratio of the horizontal depth of the external shading projection divided by the distance from the window jamb to the farthest point of the external shading projection, in consistent units.

R-value (thermal resistance): the reciprocal of the time rate of heat flow through a unit area induced by a unit temperature difference between two defined surfaces of material or construction under steady-state

conditions. Units of R are m^2-°C/W (h-ft^2-°F/Btu). For the prescriptive building envelope option, R-value is for the insulation alone and does not include building materials or air films.

Readily accessible: capable of being reached quickly for operation, renewal, or inspections without requiring those to whom ready access is requisite to climb over or remove obstacles or to resort to portable ladders, chairs, etc. In public facilities, accessibility may be limited to certified personnel through locking covers or by placing equipment in locked rooms.

Recirculating system: a domestic or service hot water distribution system that includes a close circulation circuit designed to maintain usage temperatures in hot water pipes near terminal devices (e.g., lavatory faucets, shower heads) in order to reduce the time required to obtain hot water when the terminal device valve is opened. The motive force for circulation is either natural (due to water density variations with temperature) or mechanical (recirculation pump).

Reflectance: the ratio of the light reflected by a surface to the light incident upon it

Resistance, electric: the property of an electric circuit or of any object used as part of an electric circuit that determines for a given circuit the rate at which electric energy is converted into heat or radiant energy and that has a value such that the product of the resistance and the square of the current gives the rate of conversion of energy

Reset: automatic adjustment of the controller set point to a higher or lower value

Residential: spaces in buildings used primarily for living and sleeping. Residential spaces include, but are not limited to, dwelling units, hotel/motel guest rooms, dormitories, nursing homes, patient rooms in hospitals, lodging houses, fraternity/sorority houses, hostels, prisons, and fire stations.

Return Air: Air from the conditioned area that is returned to the conditioning equipment for reconditioning. The air may return to the system through a series of ducts, plenums, and airshafts.

Roof: the upper portion of the building envelope, including opaque areas and fenestration, that is horizontal or tilted at an angle of less than 60° from horizontal

Roof area, gross: the area of the roof measured from the exterior faces of walls or from the centerline of party walls

Service: the equipment for delivering energy from the supply or distribution system to the premises served

Service water heating: heating water for domestic or commercial purposes other than space heating and process requirements

Set point: point at which the desired temperature (°C) of the heated or cooled space is set

Shading Coefficient (SC): the ratio of solar heat gain at normal incidence through glazing to that occurring through 3 mm (1/8 in) thick clear, double-strength glass. Shading coefficient, as used herein, does not include interior, exterior, or integral shading devices

Simulation program: a computer program that is capable of simulating the energy performance of building systems

Single-zone system: an HVAC system serving a single HVAC zone

Site-recovered energy: waste energy recovered at the building site that is used to offset consumption of purchased fuel or electrical energy supplies

Skylight roof ratio (SRR): is the ratio of the total skylight area of the roof, measured to the outside of the frame, to the gross exterior roof.

Slab-on-grade floor: that portion of a slab floor of the building envelope that is in contact with ground and that is either above grade or is less than or equal to 24 in below the final elevation of the nearest exterior grade

Solar energy source: source of thermal, chemical, or electrical energy derived from direction conversion of incident solar radiation at the building site.

Solar Heat Gain Coefficient (SHGC): the ratio of the solar heat gain entering the space through the fenestration area to the incident solar radiation, typically ranging from 0.9 to 0.1, where lower values indicate lower solar gain. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which is then reradiated, conducted, or convected into the space.

Space: an enclosed space within a building. The classifications of spaces are as follows for the purpose of determining building envelope requirements.

Conditioned space*:* a cooled space, heated space, or directly conditioned space.

Semi-heated space: an enclosed space within a building that is heated by a heating system whose output capacity is greater or equal to 10.7 W/m^2 (3.4 $Btu/h\text{-}ft^2$) of floor area but is not a conditioned space.

Enclosed Space: space within a building that is not conditioned space or a semi-heated space. Crawlspaces, attics, and parking garages with natural or mechanical ventilation are not considered enclosed spaces.

Standard Design: A computer representation of a hypothetical design based on the actual proposed design as per Appendix B– Whole Building Performance Method

Story: portion of a building that is between one finished floor level and the next higher finished floor level or the roof, provided, however, that a basement or cellar shall not be considered a story.

Supply Air: Air being conveyed to a conditioned area through ducts or plenums from a heat exchanger of a heating, cooling, absorption, or evaporative cooling system. Supply air is commonly considered air delivered to a space by a space-conditioning system. Depending on space requirements, the supply may be either heated, cooled or neutral.

System: a combination of equipment and auxiliary devices (e.g., controls, accessories, interconnecting means, and terminal elements) by which energy is transformed so it performs a specific function such as HVAC, service water heating, or lighting.

System, existing: a system or systems previously installed in an existing building.

Terminal: a device by which energy form a system is finally delivered, e.g., registers, diffusers, lighting fixtures, faucets, etc.

Thermal block: a collection of one or more HVAC zones grouped together for simulation purposes. Spaces need not be contiguous to be combined within a single thermal block.

Thermal Zone: It is a term used in energy simulation to represent area catered to by one air conditioning unit. With the help of the "zoning" building plans are simplified to reduce the modeler's work. Normally, within one zone usage pattern, set point temperature and other conditions are identical. Building spaces that would experience similar heating and cooling loads are generally grouped under one zone.

Thermostat: an automatic control device used to maintain temperature at a fixed or adjustable set point.

Tinted: (as applied to fenestration) bronze, green, or grey coloring that is integral with the glazing material. Tinting does not include surface applied films such as reflective coatings, applied either in the field or during the manufacturing process.

Ton: One ton of cooling is the amount of heat absorbed by one ton of ice melting in one day, which is equivalent to 12,000 Btu/h or 3.516 thermal kW.

Transformer: a piece of electrical equipment used to convert electric power from one voltage to another voltage.

U-factor (Thermal Transmittance): heat transmission in unit time through unit area of a material or construction and the boundary air films, induced by unit temperature difference between the environments on each side. Units of U are $W/m^2\text{-}^oC$ ($Btu/h\text{-}ft^2\text{-}^\circ F$).

Variable Air Volume (VAV) system: HVAC system that controls the dry-bulb temperature within a space by varying the volumetric flow of heated or cooled supply air to the space

Vent damper: a device intended for installation in the venting system or an individual, automatically operated, fossil fuel-fired appliance in the outlet or downstream of the appliance draft control device, which is designed to automatically open the venting system when the appliance is in operation and to automatically close off the venting system when the appliance is in standby or shutdown condition.

Ventilation: the process of supplying or removing air by natural or mechanical means to or from any space. Such air is not required to have been conditioned.

Visible Light Transmittance (VLT): Also known as the Visible Transmittance, is an optical property of a light transmitting material (e.g. window glazing, translucent sheet, etc.) that indicates the amount of visible light transmitted of the total incident light.

Wall: that portion of the building envelope, including opaque area and fenestration, that is vertical or tilted at an angle of 60° from horizontal or greater. This includes above- and below-grade walls, between floor spandrels, peripheral edges of floors, and foundation walls.

Wall, above grade: a wall that is not below grade

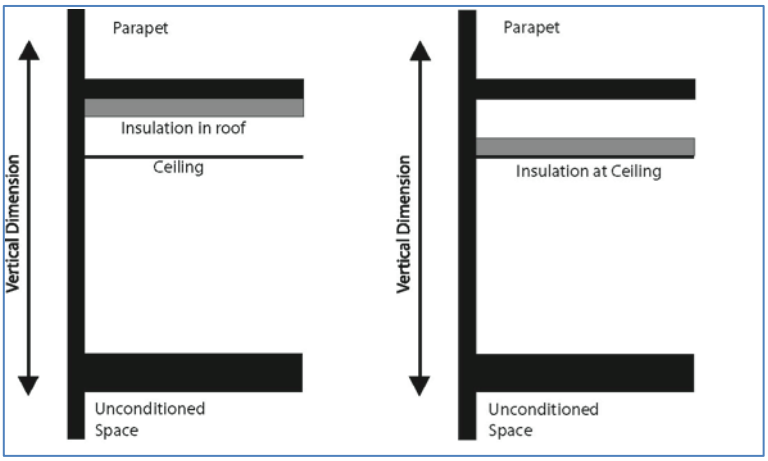
Wall, below grade: that portion of a wall in the building envelope that is entirely below the finish grade and in contact with the ground

Wall area, gross: the overall area off a wall including openings such as windows and doors, measured horizontally from outside surface to outside service and measured vertically from the top of the floor to the top of the roof. If roof insulation is installed at the ceiling level rather than the roof, then the vertical measurement is made to the top of the ceiling. (Note that does not allow roof insulation to be located on a suspended ceiling with removable ceiling panels.) The gross wall area includes the area between the ceiling and the floor for multi-story buildings.

Water heater: vessel in which water is heated and is withdrawn for use external to the system.

Weather stripping: Materials, such as a strip of fabric, plastic, rubber or metal, or a device used to seal the openings, gaps or cracks of venting window and door units to prevent water and air infiltration.

Window Wall Ratio (WWR): is the ratio of vertical fenestration area to gross exterior wall area. Gross exterior wall area is measured horizontally from the exterior surface; it is measured vertically from the



top of the floor to the bottom of the roof.

Zone, HVAC: A space or group of spaces within a building with heating and cooling requirements that are sufficiently similar so that desired conditions (e.g., temperature) can be maintained throughout using a single sensor (e.g., thermostat or temperature sensor).

10.3 ABBREVIATIONS AND ACRONYMS

AFUE	Annual fuel utilization efficiency
ANSI	American National Standards Institute
ARI	Air-Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
BIS	Bureau of Indian Standards
Btu	British thermal unit
Btu/h	British thermal units per hour
Btu/ft^2-°F	British thermal units per square foot per degree Fahrenheit
Btu/h-ft^2	British thermal units per hour per square foot
Btu/h-ft-°F	British thermal units per lineal foot per degree Fahrenheit
Btu/h-ft^2-°F	British thermal units per hour per square foot per degree Fahrenheit
C	Celsius
cfm	Cubic feet per minute
cm	Centimeter
COP	Coefficient of Performance
DOE	Department of Energy, U.S.
EER	Energy Efficiency Ratio
EC Act 2001	Energy Conservation Act 2001
EF	Energy Factor
F	Fahrenheit
ft	Foot
h	Hour
HC	Heat capacity
h-ft^2-°F/Btu	Hour per square foot per degree Fahrenheit per British thermal unit
h-m^2-°C/W	Hour per square meter per degree Celsius per Watt
hp	Horsepower
HSPF	Heating seasonal performance factor
HVAC	Heating, Ventilation, and Air Conditioning
I-P	Inch-pound
in.	Inch

IPLV	Integrated part-load value
ISHRAE	Indian Society of Heating, Refrigeration and Air-conditioning Engineers
kVA	Kilovolt-ampere
kW	kilowatt
kWh	kilowatt-hour
LE	Lighting efficacy
lin	Linear
lin ft	Linear foot
lin m	Linear meter
lm	Lumen
LPD	Lighting Power Density
m	Meter
mm	Millimeter
NAECA	National Appliance Energy Conservation Act
PF	Projection factor
PTAC	Packaged terminal air conditioner
R	R-value (thermal resistance)
SC	Shading Coefficient
SHGC	Solar heat gain coefficient
SL	Standby loss
VAV	Variable air volume
VLT	Visible light transmission
W	Watt
W/ft^2	Watts per square feet
W/m^2	Watts per square meter
W/m^2-°C	Watts per square meter per degree Celsius
W/m^2	Watts per hour per square meter
W/m-°C	Watts per lineal meter per degree Celsius
W/m^2-°C	Watts per hour per square meter per degree Celsius
Wh	Watthour

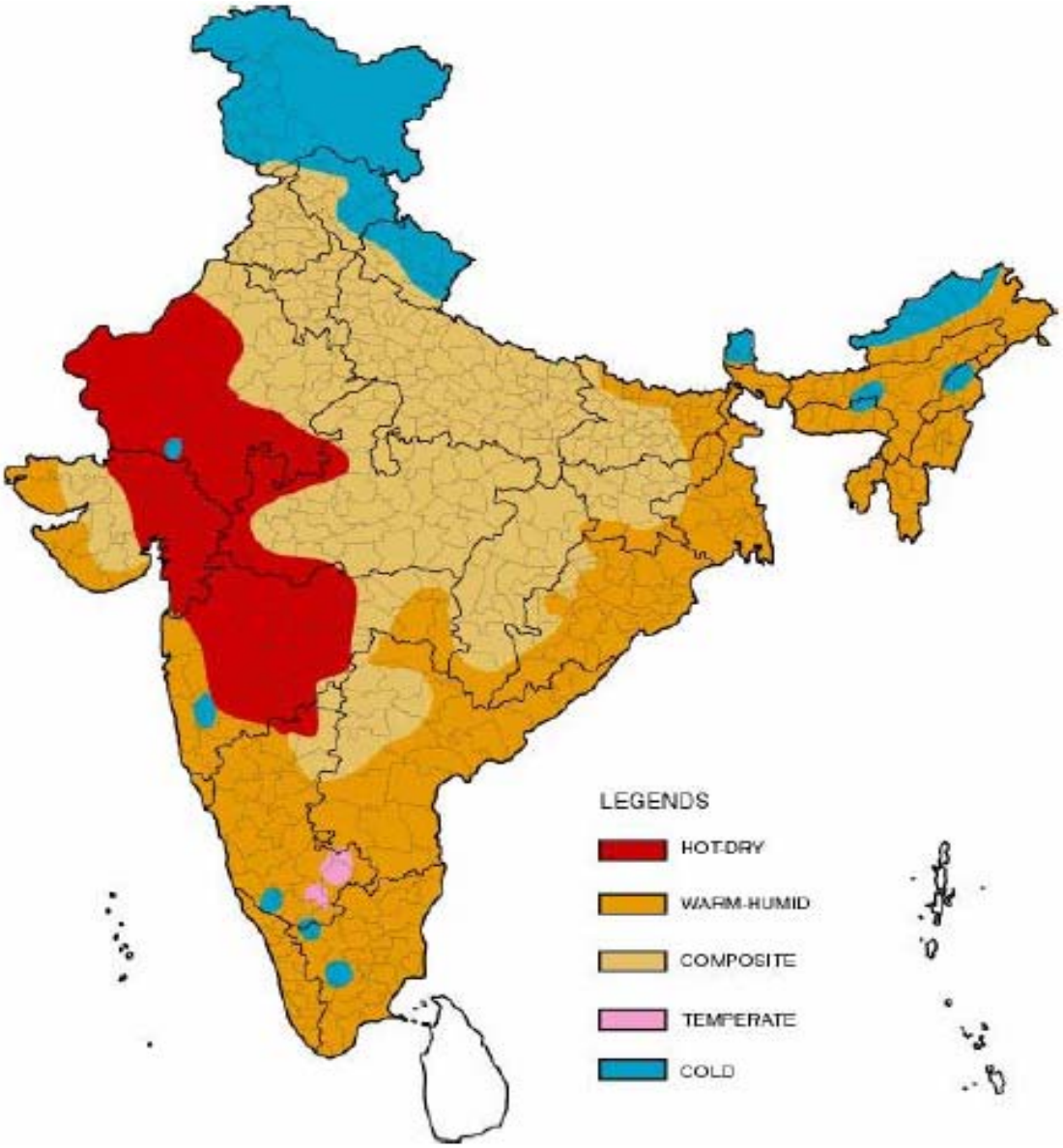
11 CLIMATE ZONE MAP OF INDIA

11.1 CLIMATE ZONES

The first step in following the ECBC is determining the appropriate climate zone of the building site which will dictate the specific requirements for design and construction of the building systems and components. India possesses a large variety of climates, which can be broadly categorized into five regions with distinct climates. The five climate zones, illustrated in the following map normally designated as hot and dry; warm and humid; composite; temperate and cold. The classification of climate for different types of buildings is an aid to the functional design of buildings. Our country is zoned into several regions such that the differences of climate from region to region are capable of being reflected in building design, warranting some special provision for each region.

The significant difference in the climatic data across these zones defines unique thermal comfort requirements for buildings located in different zones. Following broadly highlights the differences in weather data in the five climate zones and Table 36 below provides a list of major cities in India with respect to their climate zones. These differences in the weather profile translate into unique requirements for building thermal comfort and architectural responses for the different climate zones. (See in Figure36 Section 4).

Figure 36: Climate Zone Map



Source: National Building Code 2005, Part 8, Fig. 2

Table 35: Classifications of Different Climate Zones in India

Climate Zone	Description	Mean Temperature (°C)					Mean Relative humidity	Annual Precipitation	Sky Conditions	Places
		Summer midday (High)	Summer night (Low)	Winter midday (High)	Winter night (Low)	Diurnal Variation				
Hot & Dry	High temperature | Low humidity and rainfall | Intense solar radiation and a generally clear sky | Hot winds during the day and cool winds at night | Sandy or rocky ground with little vegetation |Low underground water table and few sources of surface water.	40 to 45	20 to 30	5 to 25	0 to 10	15 to 20	Very Low 25-40%	Low <500 mm/yr.	Cloudless skies with high solar radiation, causing glare	Rajasthan, Gujarat, Western Madhya Pradesh,Central Maharashtra etc.
Warm & Humid	Temperature is moderately high during day and night | Very high humidity and rainfall | Diffused solar radiation if cloud cover is high and intense if sky is clear | Calm to very high winds from prevailing wind directions | Abundant vegetation | Provision for drainage of water is required	30 to 35	25 to 30	25 to 30	20 to 25	5 to 8	High 70 to 90%	High > 1200 mm/yr.	Overcast (cloud cover ranging between 40 and 80%), causing unpleasant glare	Kerela, Tamilnadu, Costal parts of Orissa and Andhra Pradesh etc.
Temperate	Moderate temperature | Moderate humidity and rainfall | Solar radiation same throughout the year and sky is generally clear | High winds during summer depending on	40 to 35	20 to 25	30 to 32	18 to 20	5 to 8	High 60 to 85%	High > 1000 mm/yr	Mainly clear, occasionally overcast with dense low clouds in summer	Bangalore, Goa and parts of the Deccan

	topography | Hilly or high plateau region with abundant vegetation									
Cold (Sunny / Cloudy)	Moderate summer temperatures and very low in winter | Low humidity in cold/ sunny and high humidity in cold/ cloudy | Low precipitation in cold/ sunny and high in cold/ cloudy | High solar radiation in cold/ sunny and low in cold/ cloudy | Cold winds in winter | Very little vegetation in cold/ sunny and abundant vegetation in cold/ cloudy	17 to 24 / 20 to 30	4 to 11 / 17 to 21	(-7) to 8 / 4 to 8	(-14) to 0 / (-3) to 4	25 to 25 / 5 to 15	Low: 10-50% / High: 70-80%	Low: < 200 mm/yr /Moderate 1000mm/yr	Clear with cloud cover < 50% / Overcast for most of the year	Jammu &Kashmir, Ladakh, Himachal Pradesh, Uttaranchal, Sikkim, Arunachal Pradesh
Composite	This applies when 6 months or more do not fall within any of the above categories | High temperature in summer and cold in winter | Low humidity in summer and high in monsoons | High direct solar radiation in all seasons except monsoons high diffused radiation | Occasional hazy sky Hot winds in summer, cold winds in winter and strong wind in monsoons | Variable landscape and seasonal vegetation	32 to 43	27 to 32	10 to 25	4 to 10	35 to 22	Variable Dry Periods= 20-50% Wet Periods= 50-95%	Variable 500-1300 mm/yr, during monsoon reaching 250 mm in the wettest month	Variable Overcast and dull in the monsoon	Uttar Pradesh, Haryana, Punjab, Bihar, Jharkhand, Chattisgarh, Madhya Pradesh etc.

Sources:*Bansal and Minke (1988) Climatic zones and rural housing in India*
Krishan et al. (2001). Climate responsive architecture: A design handbook for energy efficient buildings

Table 36 Climate Zone of the Major Indian Cities

Indian Cities and their respective Climatic Zones			
City	Climatic Zone	City	Climatic Zone
Ahmedabad	Hot & Dry	Jorhat	Warm & Humid
Allahabad	Composite	Kota	Hot & Dry
Amritsar	Composite	Kurnool	Warm & Humid
Aurangabad	Hot & Dry	Lucknow	Composite
Bangalore	Temperate	Madras	Warm & Humid
Barmer	Hot & Dry	Manglore	Warm & Humid
Belgaum	Warm & Humid	Nagpur	Composite
Bhagalpur	Warm & Humid	Nellore	Warm & Humid
Bhopal	Composite	New Delhi	Composite
Bhubaneshwar	Warm & Humid	Panjim	Warm & Humid
Bikaner	Hot & Dry	Patna	Composite
Bombay	Warm & Humid	Pune	Warm & Humid
Calcutta	Warm & Humid	Raipur	Composite
Chitradurga	Warm & Humid	Rajkot	Composite
Dehra Dun	Composite	Ramgundam	Warm & Humid
Dibrugarh	Warm & Humid	Ranchi	Composite
Gauhati	Cold	Ratnagiri	Warm & Humid
Gorakhpur	Composite	Raxaul	Warm & Humid
Gwalior	Composite	Saharanpur	Composite
Hissar	Composite	Shillong	Warm & Humid
Hyderabad	Composite	Sholapur	Hot & Dry
Imphal	Warm & Humid	SunderNagar	Cold
Indore	Composite	Surat	Hot & Dry
Jabalpur	Composite	Tezpur	Warm & Humid
Jagdelpur	Warm & Humid	Tiruchchirapalli	Warm & Humid
Jaipur	Composite	Trivandrum	Warm & Humid
Jaisalmer	Hot & Dry	Tuticorin	Warm & Humid
Jamnagar	Warm & Humid	Veraval	Warm & Humid
Jodhpur	Hot & Dry	Vishakhapatnam	Warm & Humid

12 SUPPLEMENTAL MATERIALS

12.1 HEAT TRANSFER FUNDAMENTALS AND CALCULATIONS

12.1.1 Heat Flow Basics

Knowledge of the fundamentals of heat transfer and solar radiation are crucial in understanding the underlying processes that take place in a building and its interaction with the external environment. Various heat exchange processes are possible between a building and the external environment (Figure 37) and between a human body and a building's internal environment (Figure 38). Heat flows by conduction through various building elements such as walls, roof, ceiling, floor, etc. Heat transfer also takes place from different surfaces by convection and radiation. Besides, solar radiation is transmitted through transparent windows and is absorbed by the internal surfaces of the building. There may be evaporation of water resulting in a cooling effect. Heat is also added to the space due to the internal loads in the building which include presence of human occupants and the use of lights and equipments.

Source: Nayak & Prajapati (2006) Handbook On Energy Conscious Buildings

Figure 37: Heat exchange processes between a building and the external environment

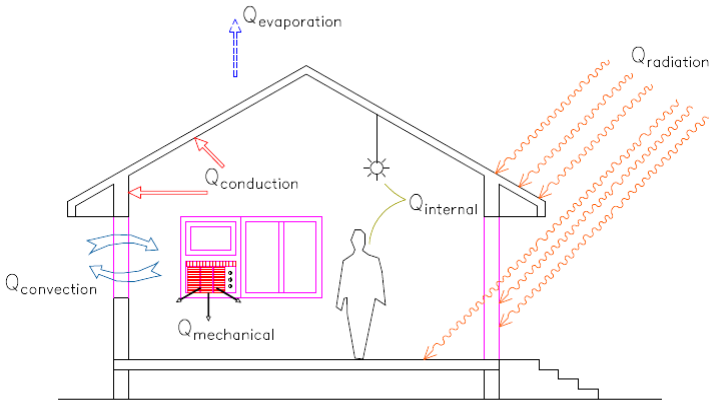
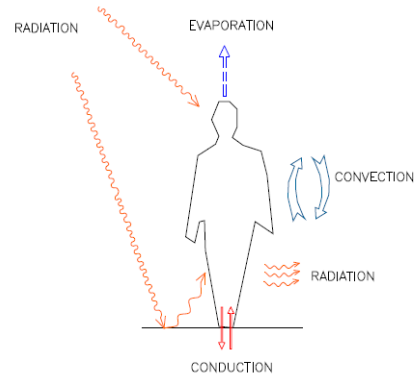


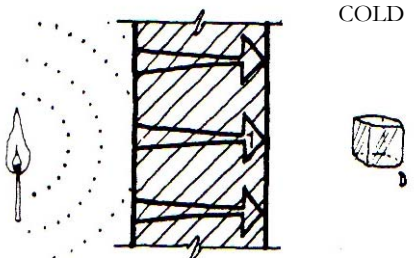
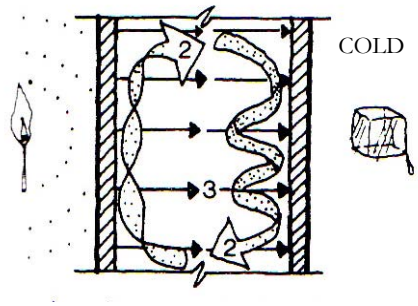
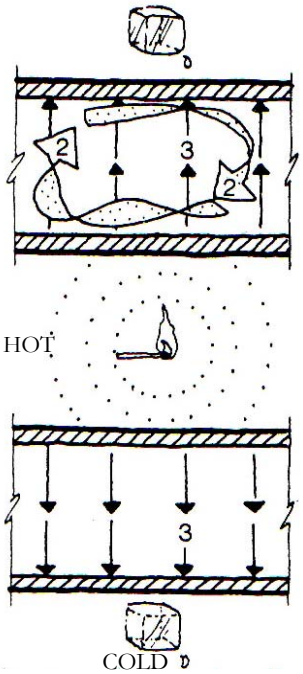
Figure 38: Heat exchange processes between a human body and the indoor environment

Source: Nayak & Prajapati (2006) Handbook On Energy Conscious Buildings



Heat flow through the various components of a building's envelope involves both heat flow through solids and heat flow through layers of air. The combination of heat flow by convection, conduction and radiation through some typical combinations of materials is shown in Figure 39.

Figure 39: Nature of heat flow through building materials and air spaces

HOT  	**Any Solid Material: Wall, Roof or Floor** A single solid material illustrates the transfer of heat from the warmer to the cooler particles by conduction (1)
HOT  	**Air Cavity in a Wall** As air is warmed by the warmer side of the air space, it rises. As it falls down along the cooler side, it transfers heat to this surface (2). Radiant energy (3) is transferred from the warmer to the cooler surface. The rate depends upon the relative temperature of the surfaces and upon their emissive and absorptive qualities. Direction is always from the warmer to the cooler surface.
 	**An air cavity in a Roof or Floor** The convective action (2) in the air space of a roof is similar to that in a wall although the height through which the air rises and falls is usually less. The radiant transfer (3) is in the upwards direction in this case because the direction is always to the cooler surface When the higher temperature is at the top of a horizontal air space, the warm air is trapped at the top, and being less dense than the cooler air at the bottom, will not flow down to transfer it's heat to the cooler surface. This results in little flow by convection. The radiant transfer in this case (3) is in the downward direction because that is the direction from the warmer to the cooler

Source: Stein & Reynolds (2000). Mechanical and Electrical Equipment for Buildings

12.1.2 Heat Flow through Conduction

Thermal conduction is the process transfer of heat from the molecules of a material at a higher temperature to the molecules of another material which is at a lower temperature. Heat can be conducted through solids, liquids and gases. At the microscopic level conduction in a solid takes place due to the vibration of atoms and molecules. In gases conduction takes place due to random motion of atoms and molecules. Some materials conduct more rapidly than others. The basic equation of heat conduction is:-

$$Q_{cond.} = \frac{k\,A\,(T_h - T_c)}{L} \quad \text{.....1.1}$$

where :-

Q_{cond} = quantity of heat flow (W)

k = thermal conductivity of the material (W/m-K)

A = area (m^2)

L = thickness (m)

T_h = temperature of the hot surface (K)

T_c = temperature of the cold surface (K)

Equation 1.1 shows that for a given temperature difference, the higher the thermal conductivity of a material of fixed thickness and cross-sectional area, the greater is the quantity of heat transferred.

The thermal conductivity and the thickness of the materials in equation 1.1 determine the overall R-value (U-value) of the building envelope component. Similarly, the T_h and T_c can be considered as the interior and exterior temperatures of the building.

Thus, the rate of heat conduction (Q_{cond}) through any element such as roof, wall or floor (Equation 1.1) can also be written as :-

$Q_{cond} = A * U * (T_h - T_c) = \ldots A * U * \Delta T$ 1.2

Where:-

A = surface area (m^2)

U = thermal transmittance (W/ m^2- K)=k/L

ΔT = temperature difference between inside and outside air (K)

The U-Value is the thermal conductance of the building element. It indicates the total amount of heat transmitted from outdoor ambient to indoor ambient through a given wall or roof per unit area per unit time. The lower the U-value, the higher is the insulating value of the element. Thus, the U-value can be used for comparing the insulating values of various building elements. It is calculated as follows:-

$$U = \frac{1}{R_T} \quad \text{.....1.3}$$

Where:-

R_T is the total thermal resistance and is given by

$$R = \frac{1}{h_i} + \left(\sum_{j=1}^{m} L_j / k_j\right) + \frac{1}{h_o} \quad \text{.....1.4}$$

Or

$$R = R_i + \left(\sum_{j=1}^{m} L_j / k_j\right) + R_o \quad \text{.....1.4 (ii)}$$

h_i and h_o respectively, are the inside and outside heat transfer coefficients and are measured in W/(m²·K). h_i and h_0 are due to convection heat transfer between solid surfaces and inside and outside air. These are also commonly referred to as film conductance or U-Value of air films (outside and inside). Surface conductance and resistances for air is given in below in Table 1.0. *hi* and L_j is the thickness of the j^{th} layer and k_j is the thermal conductivity of its material.

Table 1.0: Surface Conductances and Resistances for Air

Position of Surface	Direction of Heat Flow	Surface Emittance, ε: Non-reflective ε = 0.90 h_i	R	Reflective ε = 0.20 h_i	R	ε = 0.05 h_i	R
STILL AIR							
Horizontal	Upward	9.26	0.11	5.17	0.19	4.32	0.23
Sloping—45°	Upward	9.09	0.11	5.00	0.20	4.15	0.24
Vertical	Horizontal	8.29	0.12	4.20	0.24	3.35	0.30
Sloping—45°	Downward	7.50	0.13	3.41	0.29	2.56	0.39
Horizontal	Downward	6.13	0.16	2.10	0.48	1.25	0.80
MOVING AIR (Any position)		h_o	R				
Wind (for winter) 6.7 m/s (24 km/h)	Any	34.0	0.030	—	—	—	—
Wind (for summer) 3.4 m/s (12 km/h)	Any	22.7	0.044	—	—	—	—

Source: ASHRAE Fundamentals 2005

Equation 1.2 is solved for every external constituent element of the building i.e., each wall, window, door, roof and the floor, and the results are summed up. The heat flow rate through the building envelope by conduction is the sum of the area and the U-value products of all the elements of the building multiplied by the temperature difference.

It is expressed as:

$$Q_c = \sum_{i=1}^{N_c} A_i \, U_i \Delta T_i \quad \text{.....1.5}$$

Where:

i = building element

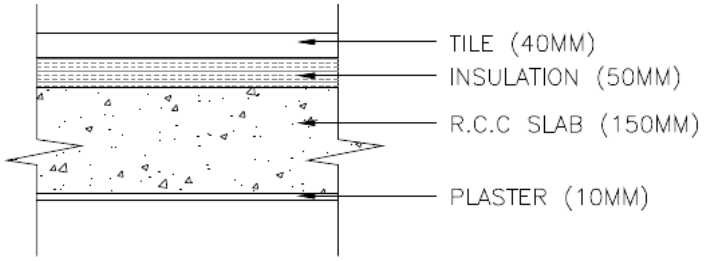
N_c = number of components

NOTE:

- The ECBC prescriptive requirements mandate minimum R-values and U-values for the different climate zones in India. These can be found in Table 4.1 (Roof assembly), Table 4.2 (Walls) and Table 4.3 (fenestration) of the ECBC.
- The steady-state thermal conductivity (k-value) and thermal resistances (R-values) of building components (walls, floors, windows, roof systems, etc.) can be calculated from the thermal properties of the materials in the component. Tables 1- 4 in Chapter 25 of the ASHRAE Fundamentals and the Appendix C of the ECBC list thermal resistances of building walls, floors, and ceilings.

EXAMPLE 1.0

Suppose we have a room that is 5 m long, 4 m wide and 3 m high. The external walls of the room are made up of 200 mm thick insulated concrete block wall. The roof of the room is made up of a RCC roof slab insulated with 5.00 cm thick expanded polystyrene (density of 24 kg/m^3), and finished with 4.00 cm thick brick tiles (density of 1760 kg/m^3) on the top, and 1.00 cm thick cement plaster on the bottom, as shown in figure below.



If the room is maintained at 23.3 ºC by an air-conditioner, what is the total heat cooling load on the HVAC system for the month of May? The daily average outside temperature in May is 32.7 ºC.

SOLUTION 1:

Cooling Load on the HVAC system is equal to the total conduction load into the room through the four walls [2 walls with surface of 15 m^2 and 2 walls with surface area of 12 m^2] and the roof (surface area 20m^2)

R_i = thermal resistance of inside air surface film (still air) = 0.16 K·m^2/W

R_o = thermal resistance of outside air surface film (24 km/h wind) = 0.03 K·m^2/W

($R_{i\ and}$ R_o values are taken from Chapter 25, Table 1: Surface Conductances and Resistances for Air of the ASHRAE Fundamentals)

First we need to estimate U-values for the building envelope:-

For the walls :-

R_{wall} = 0.37 K·m^2/W for the concrete block wall (From ECBC Appendix C)

$R_{wall\_tot} = R_o + R_{wall} + R_i$ (Using formula 1.4)

$= 0.03 + 0.37 + 0.16 = 0.56$ K·m^2/W

$U_{wall\_tot} = 1/ R_{wall\_tot} = 1.79$ W/m^2-K

The roof is comprised of 4 layers:-

Layer 1: L1=0.04 m of brick tile; k_1= 0.79W/mK (Range 0.71-0.85) from ECBC-Appendix C;

$R_1 = L_1/k_1 = 0.04/ 0.79 = 0.051$ Km^2/W

Layer 2: L_2=0.05 m of insulation; k_2= 0.35 W/(m K) from ECBC-Appendix C;

$R_2 = L_2/k_2 = 0.05/ 0.035 = 0.7$ Km^2/W

Layer 3: L_3=0.15 m RCC slab (Cement/lime, mortar, and stucco) ; k_3= 1.40 W/(m K) from ECBC-Appendix C

$R_3 = L_3/k_3 = 0.15/ 1.4 = 0.11$ Km^2/W

Layer 4: L_4= 0.01 m plaster; k_4= 0.72 W/(m K) from ECBC-Appendix C; $R_4 = L_4/k_4 = 0.01/ 0.72 = 0.014$ Km^2/W

$R_{roof} = R_o + R_{layer1} + R_{layer2} + R_{layer3} + R_{layer4} + R_i$ (Using formula 1.4)

= 0.03 + 0.051 + 0.7 + 0.11 + 0.014 + 0.016 = 0.921 W/m²-K

$U_{roof} = 1/ R_{roof} = 1.09$ W/m²-K

$\Delta T = 32.7 - 23.3$ ºC or (305.85 - 296.45 ºK) = 9.4

$A_{wall\_tot} = (2*5*3) + (2*4*3) = 54 m^2$

$A_{roof} = 5 * 4 = 20$ m²

It is calculated by $Q_{cond} = Q_{wall} + Q_{roof}$

Using formula 1.2

$Q_{cond} = (1.79 * 54 * 9.4) + (1.09 * 20 * 9.4)$

= 908.60 + 204.92

= 1113.52 W or 1.11 kW

12.1.3 Heat Flow Through Convection

Convection is the transfer of heat from one part of a fluid (gas or liquid) to another part at a lower temperature by mixing of fluid particles. Heat transfer by convection takes place at the surfaces of walls, floors and roofs. Because of the temperature difference between the fluid and the contact surface, there is a density variation in the fluid, resulting in buoyancy. This results in heat exchange between the fluid and the surface and is known as free convection. However, if the motion of the fluid is due to external forces (such as wind), it is known as forced convection. These two processes could occur simultaneously.

The rate of heat transfer (Q_{convec}) by convection from a *surface* of area A and *surrounding air* can be written as:-

$$Q_{convec} = h A (T_s - T_f) \quad \text{.....1.8}$$

Where:-

h = heat transfer coefficient (W/m²-K) ; Also referred to as film conductance or U-Value of air films

T_s = temperature of the surface (K)

T_f = temperature of the fluid (K)

The numerical value of the heat transfer coefficient depends on the nature of heat flow, velocity of the fluid, physical properties of the fluid, and the surface orientation.

Equation 1.8 calculates the convective heat transfer between a surface and its surrounding air. An alternate version of equation 1.8 can also be estimated to determine the heat flow rate due to the volume of air being circulated between the interior of a building and the outside. This heat transfer will depend on the ventilation of *air* or the rate of air exchange of air. It is given by:

$$Q_v = \rho V_r C \Delta T \quad \text{.....1.9}$$

Where:-

ρ = density of air (kg/ m^3)

V^r = ventilation rate (m^3/ s)

C = specific heat of air (J/ kg-K)

ΔT = temperature difference ($T_o - T_i$) (K)

If the number of air changes is known, then

$$V_r = \frac{NV}{3600} \quad \text{.....1.10}$$

Where:-

N = number of air changes per hour

V = volume of the room or space (m^3)

Thus, $Q_v = \rho C \frac{NV}{3600} \Delta T$ 1.11

Some of the commonly used ventilation rates for specific building types are given below in table 2.0

Table 37: Recommended Air Change Rates

Space to be ventilated	Air changes per hour
Assembly hall/ Auditorium (smoking)	3-6
Bedrooms / Living rooms (smoking)	3-6
Bathrooms/ Toilets	6-12
Cafes/Restaurants (smoking)	12-15
Cinemas/Theatres (non –smoking)	6-9
Classrooms	3-6
Factories(medium metal work - smoking)	3-6
Garages (smoking)	12-15
Hospital wards (smoking)	3-6
Kitchens (common - smoking)	6-9
Kitchens (Domestic - smoking)	3-6
Laboratories	3-6
Offices (smoking)	3-6

Source: Report on alternative building technologies, Centre for Sustainable Technologies and Department of Civil Engineering, Indian Institute of Science, Bangalore, 2003.

EXAMPLE 2:

Suppose we have a residential room that is 5 m long, 4 m wide and 3 m high. The room is maintained at 23.3 Deg.C by an air-conditioner, with a ventilation rate of 2 air changes per hour. Calculate the convective load due to ventilation?

Outdoor temperature is Daily average outside temperature is 32.7 ºC

Density of air (ρ): 1.2 kg/m3 and Specific heat of air(C): 1005 J/ kg-K

SOLUTION 2:

Using Equation 1.9 Convection load = $Q_u = \rho V_r C \Delta T$

Where:- $V_r = \frac{NV}{3600}$

Given:-

N=2; V= 5 x 4 x 3= 60 Cu.Mt ;

V_r=(5*4*3* 2) / 3600 = 0.03 ;

ΔT= 32.7-23.3 Deg. C (305.7 -296.3 K) = 9.4

$$Q_u = 1.2 * (5 * 4 * 3 * 2) / 3600 * 1005 * 9.4$$

= 377.9 W

12.1.4 Heat Transfer Through Radiation

Radiation is the heat transfer from a body by virtue of its temperature; it increases as temperature of the body increases. It does not require any material medium for propagation. When two or more bodies at different temperatures exchange heat by radiation, heat will be emitted, absorbed and reflected by each body.

The radiation exchange between two large parallel plane surfaces (of equal area A) at uniform temperatures T_1 and T_2 respectively, can be written as :-

$$Q_{12} = \varepsilon_{eff} A \sigma (T_1^4 - T_2^4) \quad \text{.....1.12}$$

with

$$\varepsilon_{eff} = [1/\varepsilon_1 + 1/\varepsilon_2 - 1]^{-1} \quad \text{.....1.13}$$

Where:-

Q_{12} = net radiative exchange between surfaces (W)

σ= Stefan-Boltzmann constant (5.67×10^{-8} W/m^2-K^4)

A = area of surface (m^2)

T_1 = temperature of surface 1 (K)

T_2 = temperature of surface 2 (K)

ε_1 and ε_2 = emissivities of surfaces 1 and 2 respectively

In case of buildings, external surfaces such as walls and roofs are always exposed to the atmosphere. So the radiation exchange (Q_{rad}) between the exposed parts of the building and the atmosphere is an important factor and is given by

$$Q_{rad} = A\varepsilon\sigma(T_s^4 - T_{sky}^4) \quad \text{.....1.14}$$

Where:-

A = area of the building exposed surface (m_2)

e = emissivity of the building exposed surface

T_s = temperature of the building exposed surface (K)

T_{sky} = sky temperature (K)

T_{sky} represents the temperature of an equivalent atmosphere. It considers the fact that the atmosphere is not at a uniform temperature, and that the atmosphere radiates only in certain wavelengths. There are many correlations suggested for expressing sky temperature in terms of ambient air temperature. Equation (1.14) can be written as:

$$\frac{Q_{rad}}{A} = h_r(T_s - T_a) + \varepsilon\Delta R \quad \text{.....1.15}$$

Where :-

T_a= ambient temperature (K)

$$h_r = \frac{\varepsilon\sigma(T_s^4 - T_a^4)}{T_s - T_a} \quad \text{.....1.16}$$

h_r is the radiative heat transfer coefficient, and ΔR is the difference between the long wavelength radiation incident on the surface from the sky and the surroundings, and the radiation emitted by a black body at ambient temperature. For horizontal surface, ΔR can be taken as 63 W/m² and for a vertical surface, it is zero.

12.1.5 Solar Heat Gain

The solar gain through transparent elements (like glazing and skylights) does not depend on the R-values/ U-Values of the surfaces, but other properties like the absorptivity of the space and transmissivity of the transparent element. Thus, the solar heat gain through transparent surfaces can be written as:

$$Q_s = \alpha_s \sum_{i=1}^{M} A_i S_{gi} \tau_i \quad \text{.....1.17}$$

Where:-

α_s = mean absorptivity of the space

A_i = area of the i^{th} transparent element (m^2)

S_{gi} = daily average value of solar radiation (including the effect of shading) on the i^{th} transparent element (W/m^2)

τ_i = transmissivity of the ith transparent element

M= number of transparent elements

Fenestration solar heat gain has two components. The quantity of **directly transmitted solar radiation** is governed by the solar transmittance of the glazing system. As shown in equation 1.17, multiplying the incident irradiance by the glazing area and its solar transmittance yields the solar heat entering the fenestration directly. **Absorbed solar radiation** is removed from the main beam and is absorbed in the glazing and framing materials of the window, and some is subsequently conducted to the interior of the building.

EXAMPLE 3:

Estimate the directly transmitted solar radiation through a single-glazed window (1.5m X 3m) on the south wall of a room that is maintained at 23.3°C by an air-conditioner.

Daily average solar radiation on south wall: 111.3 W/m²

Absorptivity of glazing for solar radiation: 0.06

Transmissivity of window: 0.86

SOLUTION 3:

Using equation 1.17 the total solar heat gain through the glazing is:-

Qs = 0.6 x 4.5 x 111.3 x 0.86 = 258.4 W

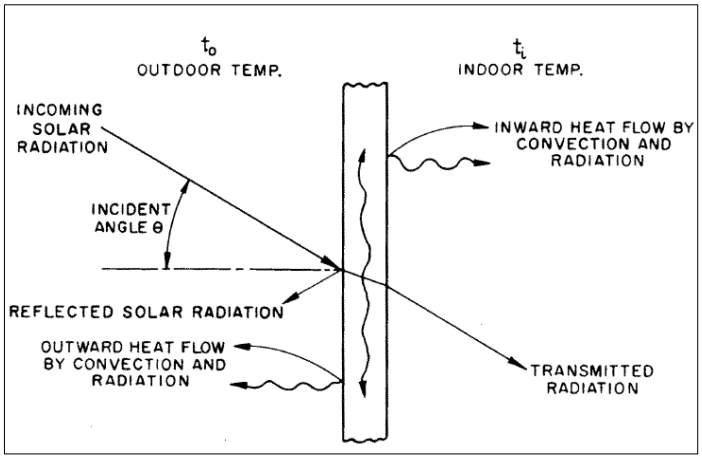
12.1.6 Heat Flow through Fenestration

Fenestration is an architectural term that refers to the arrangement, proportion, and design of window, skylight, and door systems within the building envelope. Fenestration components include a combination of glazing material, either glass or plastic; framing, mullions, dividers, and opaque door slabs; external shading devices; internal shading devices; and integral (between-glass) shading systems. Energy flows through fenestration is a complex heat transfer phenomenon where heat flow is simultaneously taking place through conduction, convection and radiation.

Heat transfer through fenestration components of the building envelope combines the following processes:-

- Conductive and convective heat transfer caused by the temperature difference between outdoor and indoor air
- Net long-wave (above 2500 nm) radiative exchange between the fenestration and its surrounding and between glazing layers
- Short-wave (below 2500 nm) solar radiation incident on the fenestration product, either directly from the sun or reflected from the ground or adjacent objects.

Fig. 36: Heat Balance for a Sunlit Glazing System



Source: ASHRAE Fundamentals Handbook 2004

Simplified calculations are based on the observation that temperatures of the sky, ground, and surrounding objects (and hence their radiant emission) correlate with the exterior air temperature. The radiative interchanges are then approximated by assuming that all radiating surfaces (including the sky) are at the same temperature as the outdoor air. With this assumption, the basic equation for the instantaneous energy flow Q through a *fenestration system* (combination of the glazing, frame and shading devices) is:

$$Q = UA_{pf}(t_{out} - t_{in}) + (SHGC)A_{pf}E_t \quad \text{.....1.18}$$

Where:

Q = instantaneous energy flow, W

U = overall coefficient of heat transfer (U-factor), W/(m²·K)

t_{in} = interior air temperature, °C

t_{out} = exterior air temperature, °C

A_{pf} = total projected area of fenestration, m^2

SHGC = solar heat gain coefficient,

E_t = incident total irradiance, W/ m^2

The principal justification for Equation 1.18 is its simplicity, achieved by collecting all the linked radiative, conductive, and convective energy transfer processes into *U* and SHGC.

NOTE:

- The *U* and SHGC are instantaneous performance indices. The SHGC indicates how well the product insulates against heat caused by sun falling directly on the glass. Lower SHGC is appropriate for hot climates to avoid added heat gain, while colder climates have higher SHGC
- The ECBC addresses energy losses through fenestration by specifying the following fenestration requirements: minimum U-Factor or Thermal Transmittance, maximum Solar Heat Gain Coefficient (SHGC), and maximum window to wall ratio (WWR) of 60% for the Prescriptive Compliance Approach

EXAMPLE 4:

Estimate the U-factor for a manufactured fixed fenestration product with a reinforced vinyl frame and double-glazing with a sputter-type low-e coating (e = 0.10). The gap is 13 mm wide and

argon-filled, and the spacer is metal.

SOLUTION 4:

Locate the glazing system type in the first column of Table 4 (Chapter 25: ASHRAE Fundamentals) (ID = 23), then find the appropriate product type (fixed) and frame type (reinforced vinyl). The U-factor listed (in the tenth column of U-factors) is 1.89 W/(m2·K).

EXAMPLE 5:

A daytime use building is located in Chennai (Warm-Humid Zone). Given the following information, estimate if the building is ECBC compliant through the prescriptive method. Also determine the total energy flow through the fenestration system on the south facade of the building

South Wall Area: 12,160 sqft

Window to Wall ratio: 1598/12160 = 13%

Fenestration Area: 1,598 sqft

Fenestration: SHCG =0.22 and U- factor =3.30

Daily average solar irradiance on south wall: 111.3 W/m^2

Outside temperature is 30 °C and the building is maintained at a temperature of 24 °C

SOLUTION 5:

According to ECBC Table 4.3, buildings located in the warm-humid climate zone can comply under the following conditions:-

1. WWW < 40% and SHGC < 0.25

Or

2. 40% <WWR≤60% and SHGC < 0.20

This building complies under the first criteria.

Fenestration Area = 1,598 sqft or 148.5 m^2

T_{out}-T_{in} = (30-24 °C) or 303.15- 297.15 °K = 6

Using equation 1.18

Q = (3.30 * 148.5 *6) +(0.22 * 148.5 * 111.3)

= 2940.3 + 3636.17

= 6576.47 W or 6.57 kW

12.1.7 Thermal Transmittance (U-FACTOR) of Fenestration

In the absence of sunlight, air infiltration, and moisture condensation, the first term in Equation 1.1.8 represents the rate of thermal heat transfer through a fenestration system. Most fenestration systems consist of transparent multipane glazing units and opaque elements comprising the sash and frame (called frame). The glazing unit's heat transfer paths include a one-dimensional center of-glass contribution and a two-dimensional edge contribution. The frame contribution is primarily two-dimensional.

Consequently, the total rate of heat transfer through a fenestration system can be calculated knowing the separate heat transfer contributions of the center glass, edge glass, and frame. (When present, glazing dividers, such as decorative grilles, also affect heat transfer, and their contribution must be considered. The overall U-factor is estimated using area-weighted U-factors for each contribution by U_o.

$$U_o = \frac{U_{cg}A_{cg} + U_{eg}A_{eg} + U_f A_f}{A_{pf}} \quad \text{.....1.19}$$

Where the subscripts *cg*, *eg*, and *f* refer to the center-of-glass, edge-of-glass, and frame, respectively. A_{pf} is the area of the fenestration product's rough opening in the wall or roof less installation clearances. When a fenestration product has glazed surfaces in only one direction (typical windows), the sum of the areas equals the projected area. Skylights, greenhouse/garden windows, bay/bow windows, etc., because they extend beyond the plane of the wall/roof, have greater surface area for heat loss than a window with a similar glazing option and frame material; consequently, U-factors for such products are expected to be greater.

NOTE:

- U-Values for fenestration products are sometimes provided for the entire glazing assembly (glass frame and shading device) or can be provide for the glazing type only. If U-values for only the glazing type have been provided, the overall U-factor needs to be calculated by including the transmittance values for the frame and the shading device (if any). Additionally, if U-values for *cg*, *eg*, and *f* are given separately, the overall U-factor for the glazing needs to be determined by using equation 1.19.

- Representative U-Factors for Various Fenestration Products in W/(m²·K) are available in Chapter 31, Table 4 2005 ASHRAE Fundamentals. The Visible Transmittance and Solar Heat Gain Coefficient (SHGC) for common glazing and window systems are available in Ta ble 13 of 2005 ASHRAE Fundamentals. These values are also available from ECBC- Table 11 for representative Unrated Vertical Fenestration (Overall Assembly including the Sash and Frame)

EXAMPLE 6:

Estimate a representative U-factor for a wood-framed, 970 by 2080 mm swinging French door with eight 280 by 400 mm panes (true divided panels), each consisting of clear double-glazing with a 6.5 mm air space and a metal spacer.

SOLUTION 6:

Without more detailed information, assume that the dividers have the same U-factor as the frame and that the divider edge has the same U-factor as the edge-of-glass. Calculate the center-of-glass, edge-of-glass, and frame areas:

A_{cg} = $8[(280 - 130)(400 - 130)]10^6$ = 0.324 m²

A_{eg} = $8(280 \times 400)\ /10^6 - 0.324$ = 0.572 m²

Af = $(970 \times 2080)/10^6 - 8(280 \times 400)/\ 10^6$ = 1.122 m²

Select the center-of-glass, edge-of-glass, and frame U-factors. These component U-factors are 3.12 and 3.63 W/(m²·K) (from Chapter 25, Table 4, ASHRAE Fundamentals 2005, glazing ID = 4, U-factor columns 1 and 2) and 2.90 W/(m²·K) (from Chapter 25, Table 4, ASHRAE Fundamentals 2005, wood frame, metal spacer, operable, double-glazing), respectively.

From Equation 1.19

$$U_o = \frac{(3.12 * 0.324) + (3.63 * 0.572) + (2.90 * 1.122)}{(0.97 * 2.08)}$$

$$= 3.14 \text{ W/m}^2\text{K}$$

12.1.8 Estimation of Heat Transfer Through Computer Based Tools

The above examples are simple illustrations of the steady state calculation of heat gain or loss for individual building elements or a single zone conditioned building. The method can also be extended to multi-zone or multi-storeyed buildings, but the algebra becomes complicated. Besides, the effects of: (a) variation of outside air temperature and solar radiation with time, (b) shading by neighbouring objects, (c) self shading (d) thermal capacity of the building (i.e. the ability of building materials to store heat during daytime and release it back to the environment later) add to the complexity of the calculations. Consequently, one resorts to computer-based tools known as building simulation tools. A number of such tools are now available to do quick and accurate assessment of a building's thermal and daylighting performance. These tools can estimate the performances of different designs of the building for a given environmental condition. From these results, a designer can choose the design that consumes minimum energy. Thermal calculations also help to select appropriate retrofits for existing buildings from the viewpoint of energy conservation. Thus, by integrating the simulation of thermal performance of a building with its architectural design, one can achieve an energy efficient building.

A number of tools are available for simulating the thermal performance of buildings; they address different needs. For example, an architect's office requires a tool that is quick and gets well integrated into the design process. On the other hand an HVAC engineer would look for a tool that would accurately predict the energy a building would consume, for optimum sizing of the air conditioning systems.

Please see Chapter 9 for computer simulation techniques for ECBC compliance under the Whole Building Performance Method

REMARKS:

The above-mentioned examples illustrate simple calculations that impact total heat transfer from buildings. Suppose we know that the total heat load of a building is 4168.7 W (4.2 kW). Now, the problem facing a designer is to make sense of this quantity.

As the total heat gain rate is positive; it represents the total heat entering the building. How does 4.2 kW translate practically? Let us consider it from two angles.

- The COP of a standard window air conditioner of 1.5 tons cooling capacity is about 2.8. So the power required is 1.5 kW (i.e., 4.2 kW/2.8)
- Suppose the machine were to be used for 8 hours a day; then it would consume 12 kWh per day (1.5 kW × 8 hours = 12) or 12 units (One kWh is equivalent to one unit) of electricity supplied by the power company. At a rate of Rs. 4 per unit, expenses would amount to Rs. 48 per day.

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